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# THE REVOLUTION IN MATERIALS SCIENCE AND ENGINEERING:
## Strategic implications for developing countries in the 1990s

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## NOTE

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## 1. INTRODUCTION AND SUMMARY: The new materials era and developing economies.*

Primary commodity, industrialisation, trade and development strategies in the 1990's must be devised in a radically different and fast changing global scientific, technological and manufacturing environment to that to which we have been historically accustomed in the major part of the post-war period. In this paper[1], we first identify those forces that have ushered in a revolution in the scientific and engineering technology base of materials design, production and use. We then link this ongoing transformation of the materials producing sectors to the emerging manufacturing technologies, as the industrialised advanced economies (IAC's) proceed along a slow and uneven transition to new methods of industrial organisation and production. It should be clear that divorcing the analysis of the materials producing industries from a thorough-going investigation of the circumstances and evolving requirements of the materials-using manufacturing industries can only result in partial understanding and misleading policy conclusions.

Decisions appertaining to materials issues require an understanding both of the trends in materials science and engineering (MSE) and of the restructuring process of IAC's. Economic forces, new market circumstances and corporate strategies are leading to a substantial restructuring, redeployment and reorientation of basic materials producing industries. This implies a reordering of the importance of regions and economies engaged in the production of traditional raw and semi-processed commodities entering domestic industry and world trade. At the same time, new technological and manufacturing conditions are leading to greater vertical integration between materials producers and materials users in industry. Thus, the materials sector is not only emerging as a high-tech in itself and a crucial determinant of technical change in other high-and science-based industries, but it is also an inseparable and necessary component of the move of the economic system towards more flexible methods of production and consumption, where materials must meet increasingly stringent performance and quality criteria.

A large number of developing economies remain heavily dependent on traditional primary commodity production and trade as a component of GDP, and in terms of employment, government revenue and foreign exchange generation, the latter acquiring even greater importance in the 1980's given the rise in external indebtness and repayment obligations. In its attempts to grapple with the well-known difficulties in this area, national and international commodity policy is at a cross-roads, beginning to recognise the need to go beyond traditional modes of thinking and remedies.

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[1] This paper draws on a much larger study by the author, entitled: 'Advanced Materials, the Restructuring of Industry and The Third World: The revolution of materials science and engineering and its implications for the global division of labour'. Institute of Development Studies, University of Sussex, (Forthcoming, March 1990) pp 160. For a more comprehensive coverage of the subject matter and greater elaboration of the arguments the reader is referred to the study above and the following: 'Advanced Materials and Primary Commodities: A review of recent scientific and technological developments and their implications for industrial policy and strategy'. Paper presented at the Expert Group Meeting on Prospects for Industrialisation Policies in Development Countries Taking into Account the Impact of Developments in the Field of New and High Technology, UNIDO, Vienna, Austria, 4-7 April 1989. A condensed version of this paper appears in 'New Technologies and Global Industrialisation' UNIDO, P.P.D 141, November 1989. See also, 'The Materials Revolution and Economic Development', IDS Bulletin, Vol 21, No 1, April 1990.

* An earlier version of this paper was presented at the ARAST2 Workshop on Materials Science and Technology, New Delhi, India, 19-24 February 1990, and the 2nd International Conference on Technology and Industrial Policy, 25-26 April, 1990, São Paulo, Brazil.

Developing economies are important participants in world trade in commodities and manufactures. It is clear that urgent measures are currently required in the areas of debt relief, lower cost and enhanced flows of external finance, tariff reform and market liberalisation together with other mechanisms to strengthen their position in commodity markets, such that the most severe difficulties can be eased, if not alleviated, and the most pressing needs met. Nevertheless, necessary as such measures might be in the short to medium run, developing economies must reassess the conditions to be met and under which it would be advisable for them to remain, exit or enter into a particular stage in commodity production, and indeed the wisdom of a resource based industrialisation strategy. For, commodity issues are becoming deeply enmeshed in the new materials and manufacturing era and emerging best practice technologies. A corollary of this is that the new circumstances are not merely relevant to those economies engaged in the production of a specific primary commodity or monolithic material. Whether an economy remains or exits from a specific commodity, it still needs to be able to operate, compete and survive in a global market place characterised by a quantum leap in the knowledge-content of materials production and use and by the diffusion of microelectronics-based automation technologies and new forms of organisation of production across all manufacturing activities. As traditional sources of comparative advantage are being eroded, the conditions for foreign direct investment, plant location, global sourcing of materials and components, and the role and physical proximity of materials suppliers in manufacturing are all changing. This then raises important issues regarding the conditions which must be met in the 1990's in the areas of infrastructure, maintenance and support industries, skills and training, testing, standards and quality assurance, such that developing economies at different stages of socio-economic development can increase their participation in global industry, technology transfer and trade. These considerations will prove most critical in the case of the least developed economies whose commodity export and trade performance in the 1980's has led to unacceptable curtailments in domestic health and education expenditures, and an inability to maintain a deteriorating infrastructure and productive capacity.

It must be stressed that the materials revolution affords tremendous opportunities and potential gains of early entry for a great many developing economies. The new materials scientific and engineering base is not only capable of spawning clusters of new advanced metals, engineering polymers, advanced ceramics, and composite material systems, but can also lead to substantial improvements in the processing and properties of existing materials. In fact, the acquisition of advanced processing and engineering competence in both new and traditional materials will be a central aspect of development and industrialisation strategies in the 1990's.

The current revolution in MSE mandates a multi-disciplinary approach to materials issues. At the same time the new circumstances lead, inescapably, to a strong transmaterial and transectoral approach to analysing and confronting issues related to materials, in contradistinction to the mono-material and specialised analyses, that proved to be adequate until recently. Boundaries and barriers between materials are eroding both at the science and production end, and at the market or end-use end, where there is significant interpenetration of materials across uses, and several materials compete for the same application.

These multi-disciplinary and trans-material aspects are beginning to have an impact across the whole spectrum of organisation of industrial R&D laboratories, university departments, educational curricula, professional societies and testing and standards institutes. For example previously specialised professional societies and associations, as in metals or polymers, are transforming themselves to (multi) materials societies. And, companies engaged in traditional and monomaterial specialisation find that they increasingly need multidisciplinary and multimaterials scientific, production and marketing competences.

Clearly the acquisition of interdisciplinary competences is also becoming a necessity and must be reflected in the institutions and government organisation of the economy at large, in order to be able to comprehend, and address the complexities, elusive nature and transectoral implications of the new materials era. Accessing, assimilating, and utilising materials information and data, as well as monitoring relevant trends in materials science and technology, and translating them into a set of appropriate domestic industrial and educational policies, requires multidisciplinary institutional capabilities within government, probably embodied in a specialised unit, council or nucleus, along the Brazilian example.

The new materials era and its attendant science and technology base necessitates the regional and international cooperation between developing countries in the areas of information and data gathering and exchange, education and training, materials science and technology research programmes and experimentation and the development of common and uniform testing, measurement and performance evaluation standards, which also conform to those being developed in IAC's. It must be stressed that in this new and advanced materials era, the acquisition of high-tech competences in measurement and performance evaluation to facilitate both development and application/diffusion of materials has become an absolute necessity for the competitive survival of economies in the 1990's. There is also a need to go beyond the networking of existing institutions and centres of excellence, and to set up international centres which can assist developing economies in both frontier scientific and engineering research and in monitoring, information gathering and dissemination, the generation of materials properties data bases and in techno-economic studies which would provide the basis for domestic industrial and educational strategic planning. The speed of change, the enormous complexity and multidisciplinary, transectoral aspects of materials issues mean that all opportunities for technical, economic and industrial cooperation between developing countries be grasped, and that collective approaches may be necessary, including the setting up of appropriate regional and international centres of excellence. Already, an International Centre for High Technology and New Materials has been set up in Trieste, Italy, and the establishment of an International Materials Assessment and Applications Centre, possibly in Brazil, has already completed its design and definition stage as a UNIDO Project.

The greater participation of developing countries in the world economy, the more efficient utilisation of world resources and the scientific and technological upgrading of these economies requires an appropriately enlarged role for IAC's industry and institutions in the framework of market liberalisation and international cooperation. Finally, and most importantly, all such aspects of resource and materials utilisation and management have become inseparable from considerations of environmental impact and sustainable patterns of development. Acceptable solutions in these areas require regional and international cooperation and agreement. It is therefore becoming increasingly clear that the vastly enhanced science and technology base of MSE and biotechnologies must increasingly be directed to meet the needs of development while minimising pressure on the environment, energy and natural resources.

## 2. THE ORIGINS, CHARACTERISTICS AND CONSEQUENCES OF THE MATERIALS REVOLUTION.

### 2.1 The origins and characteristics of the revolution in materials science and engineering.

### 2.1.1 The nature of the radical transition of MSE.

During the 1980's it has become clear that the field of materials design, production and use is in the process of being radically and irreversibly transformed. At the root of this ongoing internal transformation, which contains the seeds for widespread ramifications throughout industry and the economy, lies the revolution in Materials Science and Engineering (MSE). A number of factors acting in concert are responsible for this.

The revolutionary advance in physics during the period 1895 - 1930's, greatly expanded our ability for scientific study and understanding of the structure of solids, both crystalline and amorphous, and of the connections between the structure and properties of matter. Nevertheless, such deep and, continuously improving, insights offered by quantum physics, permeating as they did all physical sciences, could only be taken full advantage of relatively recently.

Improved understanding of the structure and composition of matter, and their relation to properties has meant an increasing ability to analyse, model, predict and control both the microstructure and associated properties of materials. Seen from the vantage point of the late 1980's, materials science and applied research, is now in possession of such greatly enhanced analytical, theoretical, predictive and control capabilities with which to manipulate and build materials at the atomic, lattice, micro and macrostructure levels, that could not even have been imagined at the beginning of the decade. For example, at the atomic level, "...instruments such as the scanning tunnelling microscope and the atomic resolution transmission electron microscope can reveal, with atom-by-atom resolution the structures of materials. Ion Beam, Molecular Beam, and other types of equipment can build structures atom layer by atom layer. Instruments can monitor processes in materials on time scales so short that the various stages in atomic rearrangements and chemical reactions can be distinguished. Computers are becoming powerful enough to allow predictions of structures and of time-dependent processes, starting with nothing more than the atomic numbers of the constituents".[2]

For centuries materials synthesis and processing relied on empiricism. In recent decades the analysis, synthesis and processing of materials has been benefiting from the incorporation of more fundamental scientific understanding, but these enhanced theoretical insights could only offer qualitative guidelines to modelling and prediction. In recent years, major new instruments (see Diagram 1), the availability of enhanced computing power able to handle vast amounts of generated data and to perform the trillions of calculations required for even the simplest of atomic arrangements, together with advances in process modelling, experimental and characterisation techniques and mathematics, have meant that materials scientists are now able to provide quantitative theoretical modelling guidelines in the design and processing path of materials. It is difficult to overstate the importance of such developments, which are beginning to provide a unified theoretical framework within which exceedingly complex problems relating to materials properties and performance in use, and the mechanisms by which they can be altered or degrade, can be addressed and new materials can be designed and developed.

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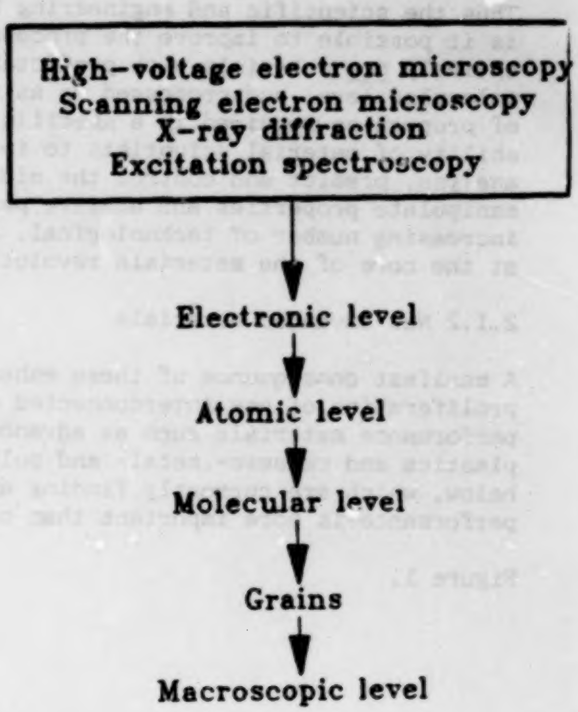
[2] Materials Science and Engineering for the 1990's; Maintaining Competitiveness in the Age of Materials. Committee on Materials Science and Engineering, U.S. National Research Council, National Academy of Sciences, 1989, p 74. The arguments below owe much to this excellent and authoritative report.

## DIAGRAM 1 NEW ANALYTICAL TECHNOLOGIES

**The development of advanced high-resolution analytical technologies has provided materials scientists with a repertoire of tools with which to probe the intrinsic electronic structure of all materials.**

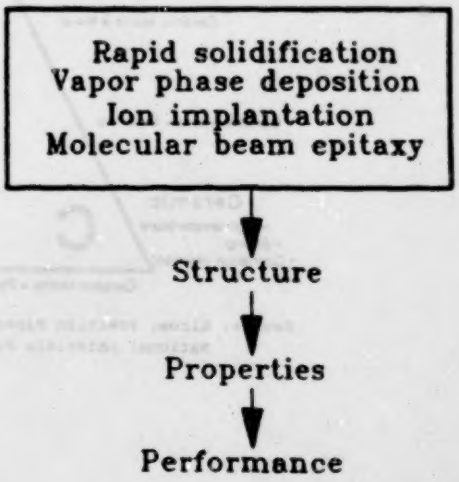
**This has led ultimately to an improved understanding of the fundamental nature of the "solid state."**


High-voltage electron microscopy
Scanning electron microscopy
X-ray diffraction
Excitation spectroscopy
Electronic level
Atomic level
Molecular level
Grains
Macroscopic level

## DIAGRAM 2 NEW MATERIALS PROCESSING TECHNOLOGIES

**New processing technologies enable scientists to alter the structure and, ultimately, the performance of materials.**

**Such advances have enabled materials scientists to improve existing materials as well as to create new manmade "engineered materials" with properties tailored to meet the special needs of the end user.**


Rapid solidification
Vapor phase deposition
Ion implantation
Molecular beam epitaxy
Structure
Properties
Performance

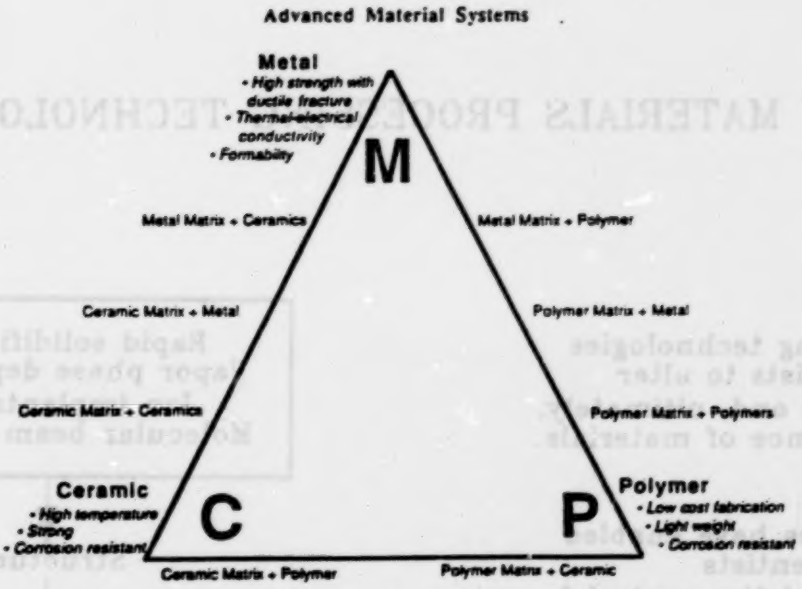
**Source:** L. Sousa, 'Problems and Opportunities in Metals and Materials'
U.S. Bureau of Mines, 1988

Thus the scientific and engineering basis of materials today is such that not only is it possible to improve the processing and properties of existing materials but entirely new materials with predictable properties can be designed at the atomic or molecular level and processed so as to acquire the characteristics or combination of properties required in a specific application. It is this, almost miraculous, ability of material scientists to intervene at the atomic or higher levels, to analyse, predict and control the microstructure along the processing path, to manipulate properties and achieve performance characteristics necessary across an increasing number of technological, industrial and military applications that lies at the core of the materials revolution.

### 2.1.2 New advanced materials

A manifest consequence of these enhanced powers in recent years has been the proliferation of new interconnected clusters of knowledge-intensive high-performance materials such as advanced metals, advanced ceramics, engineering plastics and ceramic-,metal- and polymer-matrix composites, as shown in Figure 1 below, which are currently finding application in high-technology industries, where performance is more important than cost.

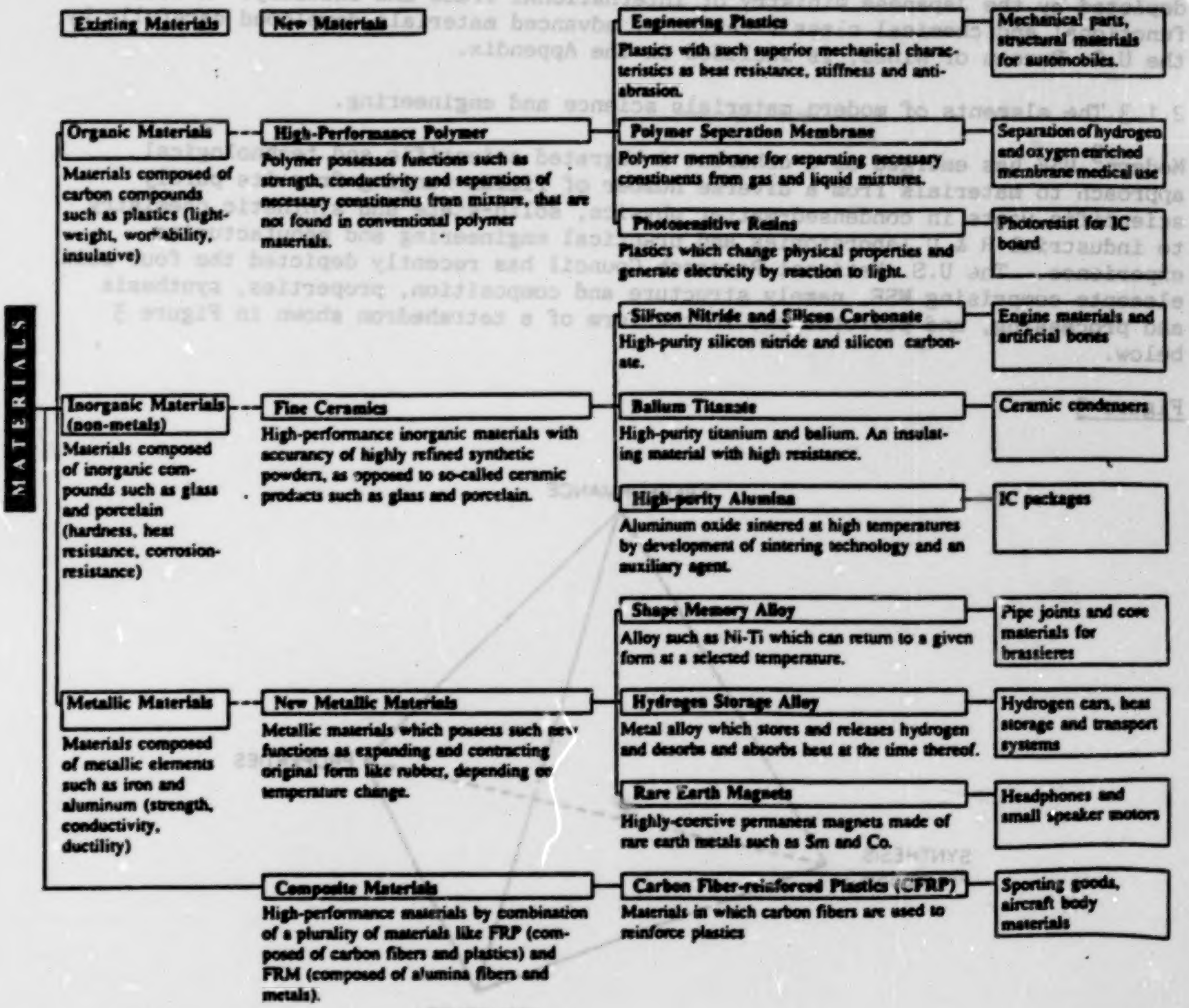
Figure 1.


Advanced Material Systems
Metal
• High strength with ductile fracture
• Thermal-electrical conductivity
• Formability
M
Metal Matrix + Ceramics
Metal Matrix + Polymer
Ceramic Matrix + Metal
Polymer Matrix + Metal
Ceramic Matrix + Ceramics
Polymer Matrix + Polymers
Ceramic
• High temperature
• Strong
• Corrosion resistant
C
P
Polymer
• Low cost fabrication
• Light weight
• Corrosion resistant
Ceramic Matrix + Polymer
Polymer Matrix + Ceramic

Source: Alcoa, Position Paper from the 10th Biennial Conference on National Materials Policy.

The arrival of advanced materials capabilities is leading to an acceleration in the rate of materials and product invention and innovation, more rapid obsolescence of products and processes, and a reduced life-cycle for new materials, which would necessitate global marketing campaigns to amortise the high R&D costs incurred. It

**Figure 2: Existing and New Materials**



**Organic Materials**

Materials composed of carbon compounds such as plastics (lightweight, workability, insulative)

**High-Performance Polymer**

Polymer possesses functions such as strength, conductivity and separation of necessary constituents from mixture, that are not found in conventional polymer materials.

**Engineering Plastics**

Plastics with such superior mechanical characteristics as heat resistance, stiffness and anti-abrasion.

Mechanical parts, structural materials for automobiles.

**Polymer Seperation Membrane**

Polymer membrane for separating necessary constituents from gas and liquid mixtures.

Separation of hydrogen and oxygen enriched membrane medical use

**Photosensitive Resins**

Plastics which change physical properties and generate electricity by reaction to light.

Photoresist for IC board

**Inorganic Materials (non-metals)**

Materials composed of inorganic compounds such as glass and porcelain (hardness, heat resistance, corrosion-resistance)

**Fine Ceramics**

High-performance inorganic materials with accurancy of highly refined synthetic powders, as opposed to so-called ceramic products such as glass and porcelain.

**Silicon Nitride and Silicon Carbonate**

High-purity silicon nitride and silicon carbonate.

Engine materials and artificial bones

**Balium Titanate**

High-purity titanium and balium. An insulating material with high resistance.

Ceramic condensers

**High-purity Alumina**

Aluminum oxide sintered at high temperatures by development of sintering technology and an auxiliary agent.

IC packages

**Metallic Materials**

Materials composed of metallic elements such as iron and aluminum (strength, conductivity, ductility)

**New Metallic Materials**

Metallic materials which possess such new functions as expanding and contracting original form like rubber, depending on temperature change.

**Shape Memory Alloy**

Alloy such as Ni-Ti which can return to a given form at a selected temperature.

Pipe joints and core materials for brassieres

**Hydrogen Storage Alloy**

Metal alloy which stores and releases hydrogen and desorbs and absorbs heat at the time thereof.

Hydrogen cars, heat storage and transport systems

**Rare Earth Magnets**

Highly-coercive permanent magnets made of rare earth metals such as Sm and Co.

Headphones and small speaker motors

**Composite Materials**

High-performance materials by combination of a plurality of materials like FRP (composed of carbon fibers and plastics) and FRM (composed of alumina fibers and metals).

**Carbon Fiber-reinforced Plastics (CFRP)**

Materials in which carbon fibers are used to reinforce plastics

Sporting goods, aircraft body materials

**Source: K. Takeda, Basic Industries Bureau, MITI**

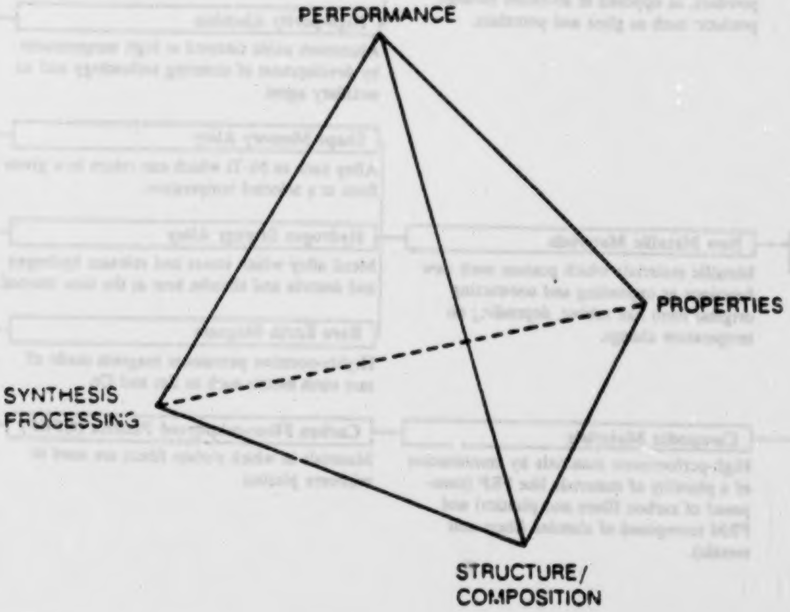
is likely that no one material will dominate the market place for long periods, as has been the case until now. Nevertheless, advanced composite systems with a synergistic combination of materials families, as shown above, are currently meeting very stringent performance criteria in a range of high-tech applications and may become the preferred materials in many applications in the first decades of the next century.

Figure 2 shows examples of differences between existing and new materials as depicted by the Japanese Ministry of International Trade and Industry. A detailed functional and chemical classification of advanced materials developed carefully by the U.S. Bureau of Mines, is included in the Appendix.

### 2.1.3 The elements of modern materials science and engineering.

Modern[3] MSE has emerged as a coherent integrated scientific and technological approach to materials from a diverse number of fields ranging from its purely scientific roots in condensed-matter physics, solid-state and synthetic chemistry to industrial R & D laboratories and practical engineering and manufacturing experience. The U.S. National Research Council has recently depicted the four main elements comprising MSE, namely structure and composition, properties, synthesis and processing, and performance, in the form of a tetrahedron shown in Figure 3 below.

Figure 3



Source: Materials Science and Engineering for the 1990's, U.S. National Research Council, Committee on Materials Science and Engineering, 1989, p.29

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[3] See U.S. National Research Council, 1989, op.cit., Ch.2 M. Kranzberg and Cyril Stanley Smith 'Materials in History and Society', Materials Science and Engineering, Vol. 37, No. 1, Jan. 1979. G.L. Liedl, 'The Science of Materials', Scientific American, October, 1986.

It is important to point out that this approach, which places at centre stage the interactions and close relationship between structure, properties, performance and processing, is both NECESSARY AND APPLICABLE TO ALL CLASSES OF MATERIALS. Secondly, the field of MSE has a strong component in pure science which is coupled to a strong engineering and industrial base. That is, improvements in existing materials or the development of new materials, entail both a deep understanding of pure science and of the fundamentals of processing and fabrication technology, as is illustrated by the development of semi conductors, lasers, composite materials and super conductors. It follows, thirdly, that as we enter the 90's, new and improved traditional materials development, processing and manufacture will come to depend on the scientific and engineering base of MSE, rendering all other empirical and craft-related approaches across the materials spectrum grossly inadequate and obsolete. Fourthly, the need to examine the many fold aspects of materials structure, composition, phenomena, characterisation, synthesis, and processing, involves the interaction of many hitherto specialised fields and disciplines, which are increasingly having to work together. All four areas have far-reaching consequences (1) for the mechanisms of incorporating scientific insight into the productive sphere, (2) the educational, infrastructural and industrial organisation requirements of the new materials age, (3) the global restructuring of basic industries and (4) the opportunities open to developing economies to enter, or remain, at various stages in the transformation of materials into useful structural and functional components and final products.

### 2.1.4 Materials science and engineering is multi-disciplinary

Materials science is now a multi-disciplinary science requiring inputs from solid state physics, chemistry, metallurgy, ceramics, composites, surface and interface sciences, mathematics, computer science, metrology and engineering. In fact, rigid separation of the different disciplines is becoming inappropriate and barriers or boundaries between them are beginning to erode. In any case, what is clear at this stage is that the nature and complexity of the problems in materials synthesis and processing is such that a joint simultaneous team effort across many disciplines, several professional staff and previously isolated research teams is now definitely required. Multi-disciplinary materials design, product development and processing capabilities are therefore becoming crucial at the level of the firm, the industry, the university, the research laboratory or the economy for that matter.

### 2.1.5 The central importance of synthesis and processing

Materials research and development now require that materials scientists become closely involved in the processing and fabrication stages of production. The micro-structure of materials, that is the arrangement of atoms into crystalline arrays or disordered structures, determines properties and performance, but the mechanism that links all of them is processing. The controlled processing path a material follows will affect microstructure and thereby properties and performance in use. Hence, materials science and engineering have now merged. A related aspect to this is that whereas in the past processing techniques were largely non-scientific and empirically based, now the science content of not only the material but, significantly, also of materials processing technology in both traditional and new advanced materials has increased by a quantum leap.

Materials scientists, across the whole spectrum of disciplines and specialisations, are therefore becoming increasingly involved in the processing and fabrication stages of materials development. Conversely, materials engineers need to be closely attuned to the scientific and theoretical aspects of materials design and modelling. This has made for a close integration of the subject matter of materials science and engineering in terms of its pure and applied aspects viewed by necessity as a coherent whole. At the same time this has led to a fruitful feedback and cross-fertilisation between scientific understanding and the engineering problem of processing materials such as to control structure and improve performance, reliability and reproducibility at low cost. The infusion of science into processing has led to several new processing technologies, without which new materials would have remained curiosities and existing materials would not have registered the tremendous improvements in properties, performance and cost that they have displayed of recent. Such new processing technologies (See Diagram 2) are being developed through the use of computer controls, sensors, process modelling, artificial intelligence, standards, in process non-destructive testing etc.

Underlying the discovery of new materials with new properties and exhibiting new phenomena (e.g. the high-temperature super-conductors in 1987), the improvements in the control of structure, composition and, hence, properties of known materials, and progress in the development of materials processing and manufacturing technologies, lies synthesis. Synthetic capabilities in the chemical and physical combination of atoms and molecules to form materials and, and its coupling to characterisation and analysis of properties, processing and manufacture is emerging as a crucial determinant of progress in pure materials research, rapidity of translating basic research to commercial application and the rate of technological change across national industrial branches and economies. Although the synthesis element of MSE necessarily retains a large scientific base, it is, nevertheless, organically connected to the processing and manufacture of solid materials. For, not only does the choice of synthetic reactions, as in the preparation of high purity powders for advanced ceramics fabrication, influence subsequent processing paths, but also modern fabrication technologies involve the merging of the synthesis and processing stage into a simultaneous process, as in injection molding of plastics. Thus, materials synthesis, processing, fabrication and manufacturing are merging in response both to forces internal to MSE, and, to pressures emanating from the evolution of new production technologies, as well as the ever increasing need to transmit, fast and efficiently, materials pure research into industrial and military application.

At present, a major constraint in the diffusion of advanced materials into a wide range of technologies and industrial applications is the ability to process raw or synthesized substances into reliable, high-volume, low cost useful forms, such as films, wire, components, devices and structures entering complex engineering systems. This is no more evident than in advanced structural ceramics, composites, and the new high-temperature superconductors. But more than this, it is becoming clear that technological competence in materials processing and fabrication is the critical component in international competitiveness of national industrial structures and industrial branches engaged in traditional and high-technology activities. Such processing capabilities facilitate more rapid translation of research results to commercial applications, and the generation of higher quality, more reliable, low-cost products of innovative design in a wide range of increasingly sophisticated manufacturing industries. This is evident from Japanese and South Korean experience, where manufacturing capabilities and associated materials processing technologies have been developed in parallel, to great advantage in terms of innovation and global competitive advantage. This is clearly an area that economies such as Brazil must pay an increasing and close attention to in a national, integrated materials, technology and industrial strategy.

### 2.1.6 The integration of materials producers and users

Increasingly, the synthesis, design and processing of a material must be integrated with the design and manufacturing path of the end-user. Materials design, component, sub-assembly and computer-aided product design engineering and manufacture are merging and require close integration and iterative interaction. In some cases, the design and manufacture of the material and of the component or end-product is a simultaneous process involving large teams of specialists as in advanced composites applications in aircraft or automobiles.

## 2.2 New and improved materials in the transition to Post-Fordism.

### 2.2.1 From Fordism to Post-Fordism

In the last 15 years a major discontinuity has appeared in the post-war pattern of mechanisation and work organisation which was based on inflexible, mass-production techniques. Industry is undergoing fundamental restructuring in the process of which there is a transition away from Fordist production practices characterising the post-war period toward increased flexibility. The emerging paradigm constituting a break from the characteristics and practices in industrial organisation, social relations and institutions associated with the previous era, can be broadly termed as Post-Fordism.

Fordist mass production methods employ the principles of increasing division of labour, fragmentation of tasks, mechanisation of tasks and employment of dedicated machinery, and moving production lines, together with Taylorist principles for managerial control of work via the separation of direct from indirect tasks, complete job specification and removal of any worker control over the work flow. Profitable production under this, admittedly, authoritarian and hierarchical labour management system in which labour skill, initiative and creativity are mostly eliminated, requires uninterrupted, high volume output of standardised products aimed at mass markets. Production here is supply driven, and utilises substantial work in progress and finished good inventories, to offset faults and quality problems and to meet fluctuations in demand. Dedicated plants and production lines make sense in conditions of very high volume, small product variety, and long product life-time and a stable macroeconomic environment in which incomes and tastes can accommodate what is emerging out of mass-production lines.

Market demand has become increasingly fragmented and unstable with consumer preferences necessitating higher quality, greater variety, low volume production of products with shorter life-cycles. Hence the inflexible manufacturing methods and accompanying inventory systems characterising Fordist production lines have become increasingly unsuitable in conditions of product differentiation, consumer sophistication, and fast changing market circumstances. Firms increasingly need to be more flexible and in close contact with the market for recognizing and speedily responding to changing demand patters. Greater variety needs to be produced in small lot sizes.

New patterns of work organisation and methods of manufacturing are emerging[4] and are diffusing throughout manufacturing in IAC's. What can broadly be described as the Just-in-Time concept of production evolved in Japan during the late 50's-70's, as an attempt, at first, to reduce inventory costs. As is currently employed, JIT lays emphasis at the demand side of the market, with close integration to customer preferences, an ability to offer large product variation and choice to consumers, and fast delivery times. Thus production is driven by a fragmented demand, and hence requires flexible patterns of work organisation and machines in order to be able to respond in a cost effective manner. Flexibility in output requires a multiskilled labour force operating in the framework of a flexible manufacturing process capable of fast, efficient changeovers to different products of small lot sizes. In this scheme of work organisation, labour is given more autonomy and responsibility in the context of more skills and multitask competence, and is paid in accordance to skill and not task as before. The central feature of the new system is a shift to multiskilling and flexible working practices of the labour force. this facilitates the reorganisation of production so as to dramatically reduce inventories of work in progress and final goods, and to introduce a zero-defect policy which is crucial to flexibility and the very functioning of JIT. Quality control now is the responsibility of workers at the point of production and requires decision making and rectification of errors by the worker. Flexibility, responsibility and quality control thus go hand in hand.

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[4] See R. Kaplinsky, 'Restructuring Industrialisation', IDS Bulletin, Vol.20, no.4, 1989.
________, 'Restructuring the Capitalist Labour-Process', Cambridge Journal of Economics, Vol.12, no.4, 1988.
________, 'Electronics-Based Automation Technologies and the Onset of Systemo-facture', World Development, Vol.13, no.3, 1985.
See R.J. Schonberger, 'Japanese Manufacturing Techniques', Free Press, 1982.
________, 'World Class Manufacturing', Collier Macmillan, London, 1986.

Evidence suggests that organisational change per se can produce great gains even with existing technologies, that it is a prerequisite to introducing automation technologies, and that most of the gains derived from new technology owe their origins to new patterns of work organisation, management-labour relations and flatter hierarchical structures.

Such trends in terms of skill requirements of the labour process and the primacy of organisational and managerial change accompanying this transitional conjuncture, contain both threats to developing economies where skilled labour is in short-supply, and opportunities to those economies and sectors which can appropriate new work practices as the basis of incremental innovation and enhanced efficiency in production for the domestic or the world market, without recourse to expensive flexible automation technologies. This is especially so in designer-dominated sectors such as clothing, footwear, and furniture, where distinct possibilities exist for horizontal inter-firm collaboration, the sharing of research, development, marketing or designing costs and new forms of state and local-government collaboration with private industry, as the overworked experience of the 'Third Italy' illustrates, and the new Cyprus industrial strategy[5] aims for.

Of course, new forms of inter-firm relationships are a prevalent feature of the emerging Post-Fordist paradigm, in part due to the new market and competitive circumstances, and in part due to the technological and organisational features associated with the spread of flexible automation technologies in manufacturing. For example, materials, components and sub-assemblies suppliers are necessarily forging greater two-way vertical linkages with user and final-assembly manufacturers due to both design interactions and technological requirements of the production process, such as are introduced by the trend towards near-net-shape manufacture and the consequent elimination of various processing stages and assembly operations. Final assemblers cultivate and upgrade a small select group of suppliers which are then encouraged to innovate and participate in the quality drive and product design and renewal of the user firm. The recent trend towards modular manufacturing reinforces these vertical forms of collaboration between suppliers and user firms, while leading to enhanced bargaining power on the part of materials and component suppliers. Thus the role of suppliers is emerging as paramount in the new manufacturing era and the diffusion of new best-practice techniques across traditional and new sectors, in both developed and developing economies. A further complication is that the new circumstances necessitate location of plant close to the market, while the employment of JIT organisation of production implies the need for suppliers to be in close physical proximity to the user firm. These observations raise the issue of the conditions which need to be fulfilled for an enlarged role of developing economies in the 1990's, as suppliers of materials, components and sub-assemblies to domestic or regional industry, and the world market. An economy lacking an appropriate, and high quality, network of suppliers may be eliminated from direct investment or global sourcing consideration while, on the other hand, an investing firm may wish to create from scratch and cultivate its own network of local input suppliers. At the same time, the absorption of new best practice techniques by domestic industry implies the creation of appropriate networks and collaborative arrangements with local or regional suppliers and the creation of networks of maintenance and support industries, including software and repair services.

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[5] See R. Murray, et.al., 'Cyprus, industrial strategy: report of the UNDP/UNIDO mission', Brighton: IDS, Univ. of Sussex, 1987.

The foregoing highlight the need for a closer look at the role of materials supplies in the new manufacturing conditions, and it is to this that we now briefly turn.

### 2.2.2 Materials in the transition of IAC's towards post-Fordist industrial organisation

It is in fact wrong to analyse materials issues in a vacuum, as if organically disconnected from the socioeconomic, scientific and technical transformation of industrial capitalism. The process of transition of IAC's from mass-production techniques to more flexible patterns of production are integrally linked to the search for and delivery of a vast array of new materials. The emerging pressures for quality and reliability from the side of the consumer and of the manufacturer could only be met by an increasingly capable MSE whose philosophy was directed towards meeting the needs of end users for flexibility and higher performance specifications offering high marketing premiums in the market place.

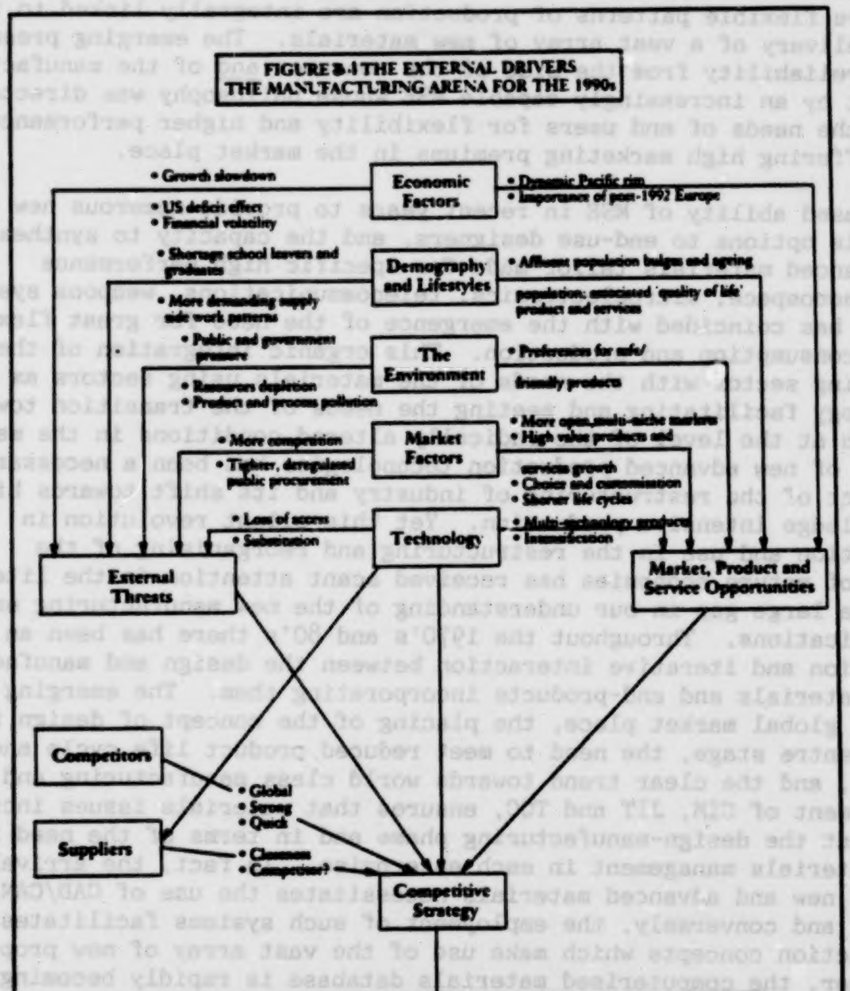
The vastly increased ability of MSE in recent years to provide numerous new and improved materials options to end-use designers, and the capacity to synthesize entirely new advanced materials tailor-made for specific high performance applications in aerospace, microelectronics, telecommunications, weapons systems and automobiles, has coincided with the emergence of the need for great flexibility at the level of consumption and production. This organic integration of the materials producing sector with the needs of the materials using sectors as an enabling technology facilitating and meeting the needs of the transition toward post-Fordism both at the level of the radically altered conditions in the market and at the level of new advanced production technologies has been a necessary and inseparable aspect of the restructuring of industry and its shift towards high-value added knowledge intensive production. Yet this silent revolution in materials production and use in the restructuring and reorganising of the industrial base of mature economies has received scant attention in the literature, and constitutes a large gap in our understanding of the new manufacturing era and its global ramifications. Throughout the 1970's and 80's there has been an ever greater integration and iterative interaction between the design and manufacturing process of new materials and end-products incorporating them. The emerging pressures of the global market place, the placing of the concept of design for manufacture at centre stage, the need to meet reduced product life cycle and fast product renewals, and the clear trend towards world class manufacturing and its attendant employment of CIM, JIT and TQC, ensures that materials issues increase in importance both at the design-manufacturing phase and in terms of the need for careful total materials management in each enterprise. In fact, the arrival of a proliferation of new and advanced materials necessitates the use of CAD/CAM in the user-industries, and conversely, the employment of such systems facilitates new design and production concepts which make use of the vast array of new properties on offer. Further, the computerised materials database is rapidly becoming the critical element in CAD, finite element analysis and its link to Computer-Aided-Manufacturing and Computer-Aided-Engineering, especially in the context of a move towards CIM by the firm. These considerations will acquire critical importance in manufacturing strategies in the 1990's in developing regions, especially in the NIC's in Latin America and S.E. Asia.

The advent of advanced materials, fast on the heels of the microelectronics revolution and diffusion, and, increasingly, linked to it, will further complicate the restructuring process under way in IAC's, further undermine traditional sources of comparative advantage in the Third World in raw and semi-processed commodity production, and radically alter the conditions for global location of industry,

**licensing and transfer of technology and the sourcing of materials and components in comparison to the recent Fordist patterns on an international scale. It is thus clear that the advent of new advanced materials and information technologies closely linked to the restructuring process of IAC's and socio-technical transition to Post-Fordism, have altered the world industrial landscape almost unrecognisably in the 1990's, offering new options and new dangers to developing economies, which have not yet been adequately identified and analysed in a coherent, comprehensive framework.**

**The figure below, summarises the new market and competitive environment faced by manufacturing industry, both materials producers and users, in the 'triad' markets of U.S., Europe and Japan, and increasingly the first and second tier NIC's.**

FIGURE B-4 THE EXTERNAL DRIVERS
THE MANUFACTURING ARENA FOR THE 1990s


Economic Factors
• Growth slowdown
• US deficit effect
• Financial volatility
• Dynamic Pacific rim
• Importance of post-1992 Europe
Demography and Lifestyles
• Shortage school leavers and graduates
• More demanding supply side work patterns
• Affluent population bulges and ageing population; associated 'quality of life' product and services
The Environment
• Public and government pressure
• Resources depletion
• Product and process pollution
• Preferences for safe/friendly products
Market Factors
• More competition
• Tighter, deregulated public procurement
• More open,multi-niche markets
• High value products and services growth
• Choice and customisation
• Shorter life cycles
Technology
• Loss of access
• Substitution
• Multi-technology products
• Intensification
External Threats
Market, Product and Service Opportunities
Competitors
Suppliers
• Global
• Strong
• Quick
• Closeness
• Competitor?
Competitive Strategy
The New Product Process
Rational Factory
Integrated Logistics
Integrated Organisation
Integrated Information

**Source: P.A. Consulting Group, 1989**

## 3. PRIMARY COMMODITIES, BASIC MATERIALS INDUSTRIES AND DEVELOPING ECONOMIES.

### 3.1 The experience of the primary commodity sector.

### 3.1.1 The continuing importance of primary commodities for LDC's.

The value of non-fuel primary commodity exports as a percentage of total developing country exports has fallen from 55.9% in 1970 to 25.9% in 1984, while that of manufactures has risen from 24.9% to 40.1% and petroleum from 19.2% to 34% over the same period, with considerable variations between regions, as shown in Table 1. Clearly, the rising importance of manufacturing and fuel exports bears a large part of the responsibility for the declining dependence of developing countries as a whole on commodity exports. Factors operating on the supply, demand and prices of commodities have also contributed to this, and they are briefly examined below.

These figures though mask considerable variation between countries. It is a sobering fact that despite progress on manufacturing exports, the majority of developing economies still remain largely dependent on primary commodity production and exports for a major part of their foreign exchange earnings. The primary commodity export sector, with its varying, but generally low degrees of downstream processing, has remained for most developing countries the backbone of economic activity and their development process.

Recent UNCTAD[6] calculations, indicate that agricultural and mining production is the single most important component of GDP for all developing countries, except the fast growing manufacturing exporters, and that for most, the share in GDP is more than 30 per cent as compared to less than 10 per cent in the developed market economies. Moreover, for more than 80 developing countries the share of primary commodities in total export earnings is above 50 per cent. In many cases, and especially for low income countries, it is also accompanied by a high degree of export concentration on one or two primary products. In 1986, the share of non-oil primary commodity exports in total exports of the 42 least developed countries, according to UNCTAD, was 65%. One group of problems often cited for the disappointing performance of commodity exporters relates to commodity export and price instability, slow or declining growth in real export earnings and/or volumes, and a long run deterioration in the real prices of their commodities. In 1986, the barter terms of trade for non-fuel primary exports were below half the high levels in 1950, according to the World Bank, which also predicts that by the year 2000 non-fuel commodity prices will only be 8 per cent higher in real terms than in 1986 and hence 25 per cent below 1980 levels. Following the relatively strong market position of commodities in the 1970's accompanied by a large expansion of capacity, the 1980's have witnessed massive overcapacity and over-supply in many commodity markets, coupled with a slump in prices until recently, as shown in Figure 4.

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[6] See UNCTAD, TD/328/Add.3, 1987.

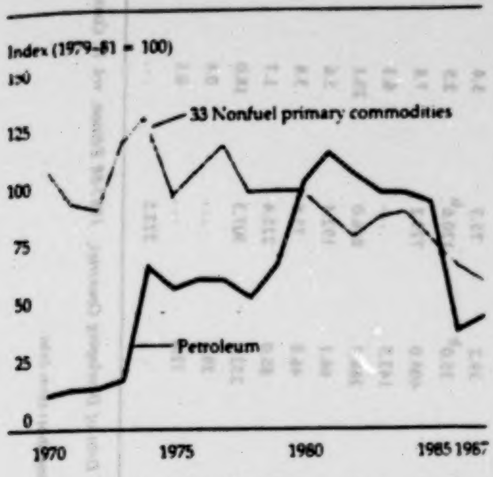
**Table 1. SHARE OF PRIMARY COMMODITIES AND MANUFACTURES IN TOTAL EXPORTS, 1970, 1980, and 1984**

| | Exports, fob, (billion current US dollars) | | | Percentage of Total Exports | | |
|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1984 | 1970 | 1980 | 1984 |
| **DEVELOPING COUNTRIES** | | | | | | |
| **Primary Commodities** | | | | | | |
| America | 11.2 | 45.1 | 43.1 | 65.9 | 43.3 | 38.2 |
| Africa | 8.3 | 23.2 | 18.3 | 70.3 | 23.8 | 30.4 |
| Asia | 9.3 | 47.4 | 44.2 | 43.1 | 21.1 | 18.7 |
| Others[2] | 1.9 | 7.3 | 7.9 | 44.2 | 27.9 | 28.1 |
| Total | 30.6 | 23.0 | 113.5 | 55.9 | 27.2 | 25.9 |
| **Petroleum[3]** | | | | | | |
| America | 4.1 | 41.5 | 43.8 | 24.1 | 39.9 | 38.8 |
| Africa | 1.8 | 50.2 | 33.8 | 15.3 | 51.6 | 56.1 |
| Asia | 4.5 | 88.5 | 69.9 | 20.8 | 39.4 | 29.6 |
| Others[2] | - | 1.4 | 1.1 | - | 5.3 | 3.9 |
| Total | 10.5 | 181.6 | 148.6 | 19.2 | 40.2 | 34.0 |
| **Manufactures[4]** | | | | | | |
| America | 1.7 | 17.5 | 26.1 | 10.0 | 16.8 | 23.1 |
| Africa | 1.7 | 23.9 | 8.1 | 14.4 | 24.6 | 13.5 |
| Asia | 7.8 | 88.6 | 122.2 | 36.1 | 39.5 | 51.7 |
| Others[2] | 2.4 | 17.5 | 19.0 | 55.8 | 66.8 | 68.0 |
| Total | 13.6 | 147.5 | 175.4 | 24.9 | 32.6 | 40.1 |
| **Total Exports** | | | | | | |
| America | 17.0 | 104.1 | 112.9 | 100.0 | 100.0 | 100.0 |
| Africa | 11.8 | 97.3 | 60.3 | 100.0 | 100.0 | 100.0 |
| Asia | 21.6 | 224.5 | 236.3 | 100.0 | 100.0 | 100.0 |
| Others[2] | 4.3 | 26.2 | 28.0 | 100.0 | 100.0 | 100.0 |
| Total | 54.7 | 452.1 | 437.5 | 100.0 | 100.0 | 100.0 |
| **INDUSTRIAL MARKET ECONOMIES** | | | | | | |
| Primary Commodities[1] | 49.0 | 241.9 | 210.9 | 22.4 | 19.9 | 17.6 |
| Petroleum[3] | 7.6 | 90.3 | 95.4 | 3.5 | 7.4 | 7.9 |
| Manufactures[4] | 162.1 | 884.8 | 894.0 | 74.1 | 72.7 | 74.5 |
| Total Exports | 218.7 | 1,217.0 | 1,200.3 | 100.0 | 100.0 | 100.0 |

1. SITC 0 plus 4 and 68 (includes non-ferrous metals)
2. United Nations data for other developing countries is obtained as a residual figure and does not necessarily reflect the actual export performance of the countries/areas involved
3. SITC 3
4. SITC 5 to 19 excluding 68 (excludes non-ferrous metals)

Source: Commodity Trade and Price Trends, World Bank, 1987-88 edition, Table 1

Figure 4: Real Commodity Prices 1970-1987



*Note:* Real prices are annual average nominal prices in dollars, deflated by the annual change in the manufacturing unit value index (MUV), a measure of the price of industrial country exports to developing countries.

Source: World Bank, World Development Report, 1988, p.25

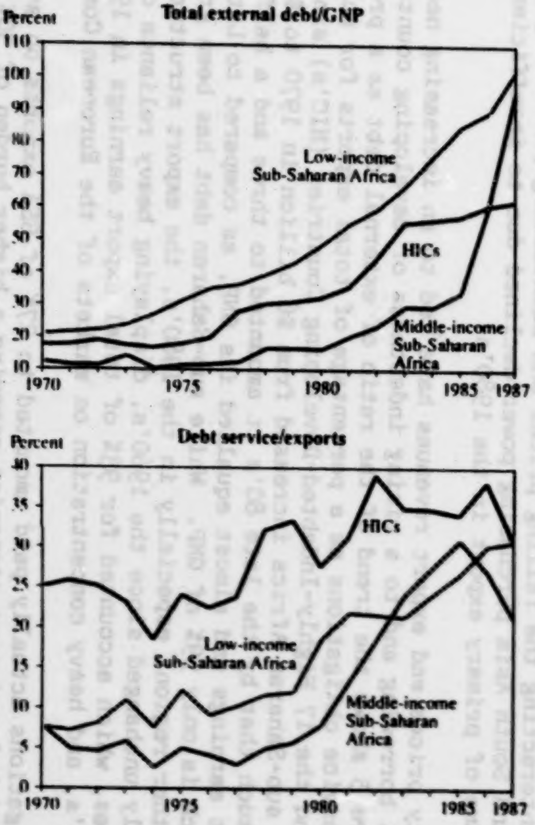
Exchange rate movements exacerbated these trends, leading to severe problems for many developing countries, in particular in sub-Saharan Africa where import capacity and government revenues and expenditures have been dramatically curtailed and per capita income has been dropping since 1980.

The worst hit region was sub-Saharan Africa (SSA), where the combination of falling prices and stagnation in primary export volumes, led to a sharp decline in real purchasing power. In contrast, the volume of primary commodity exports increased in East Asia, counteracting the falling prices and maintaining purchasing power. In Latin America and South Asia purchasing power declined due to insufficient growth in the volume of primary export in the 1980's.

Declining commodity prices and export revenues have led to an increasing need for external financial borrowing and to a rising indebtness of developing countries in the 1980's. Figure 5 shows the trend of the ratio of external debt as a proportion of GNP and debt service obligations as a percentage of total exports for sub-Saharan African and the 17 Highly-Indebted-Developing Countries (HIC's) since 1970. The total debt of sub-Saharan Africa increased from $6 billion in 1970 to $134 billion in 1988, such that by the late 80's it amounted to three and a half times the regions export earnings and almost equalled its GNP, as compared to Latin American debt which is only 59% of GNP. While sub-Saharan debt has been growing faster than any other region, especially in the 1980's, the export structure has remained relatively unchanged since the 1960's, displaying heavy reliance on primary commodities, which accounted for 93% of total export earnings in 1970 and 88% by the mid-80's, and heavy concentration on markets of the European Community.

Debt service obligations actually paid amounted to 27% of SSA exports on average between 1985-88, with low income economies carrying a higher burden of 30%. The severest difficulties are faced by the low-income SSA with debt ratios double those of middle-income HIC's and three times those of low-income Asian countries. But middle-income a per capita GNP a third of the latter, and a high export concentration on few primary commodities.

**Figure 5 External debt of Sub-Saharan Africa and highly indebted countries, 1970-87**



*Note:* HICs refers to the group of 17 highly indebted developing countries, listed in World Bank 1988h, of which two are in Sub-Saharan Africa. Total external debt is outstanding and disbursed long-term debt, short-term debt (1977-87), and IMF credit. Debt service is interest and amortization for long-term debt. Exports are goods and services. Percentages are based on debt in current dollars.
*Source:* World Bank data.

Table 2: **Selected developing economies of the ESCAP region. Indicators of the weight of indebtedness**

| | *Debt outstanding/GNP* | | *Debt outstanding/exports (Per cent)* | | *Debt-service ratio*[a] | |
|---|---|---|---|---|---|---|
| | *1980* | *1986* | *1980* | *1986* | *1980* | *1986* |
| **Republic of Korea** | 49.3 | 47.4 | 131.8 | 107.5 | 12.2 | 16.7 |
| **Indonesia** | 27.9 | 58.5 | 94.1 | 278.1 | 7.9 | 29.3 |
| **India** | 11.9 | 19.1 | 157.3 | 276.1 | 8.8 | 18.1 |
| **Philippines** | 49.4 | 93.6 | 217.4 | 326.3 | 7.2 | 18.3 |
| **Pakistan** | 38.7 | 39.0 | 329.9 | 343.2 | 19.7 | 26.8 |
| **Thailand** | 25.1 | 44.7 | 96.3 | 154.0 | 5.0 | 16.7 |
| **China** | 2.8 | 8.8 | 39.2 | 75.3 | 5.4 | 7.9 |
| **Malaysia** | 21.9[b] | 76.2[b] | 35.0[b] | 120.6[b] | 2.5 | 13.7 |
| **Bangladesh** | 31.5 | 50.6 | 404.0 | 729.2 | 7.8 | 25.1 |
| **Sri Lanka** | 48.1 | 64.4 | 143.5 | ... | 6.3 | ... |
| **Burma** | 25.9 | 45.2 | 268.7 | 846.0 | 20.1 | 55.4 |
| **Papua New Guinea** | 29.2 | 95.6 | 66.1 | 192.4 | 5.6 | 12.4 |
| **Fiji** | 23.7 | 33.0 | 46.8 | 75.6 | 3.4 | 10.0 |
| **Nepal** | 10.4 | 29.0 | 85.0 | 225.4 | 1.7 | 9.2 |
| **Samoa** | ... | 68.4 | 232.5 | 307.3 | 18.0 | 24.0 |
| **Maldives** | 108.2 | 121.2 | 39.5 | ... | 0.4 | ... |
| **Solomon Islands** | 16.7 | 64.8 | 22.8 | ... | 0.1 | ... |
| **Vanuatu** | ... | ... | ... | 222.5 | ... | 2.1 |

*Source:* World Bank, *World Debt Tables: External Debt of Developing Countries, 1987-88 Edition*, vol. II, *Country Tables* (Washington, D.C., 1988).

[a] Public and publicly guaranteed debt. [b] Excluding short-term debt.

**Table 2.1**

## LATIN AMERICA: EXTERNAL DEBT

| | Debt[a] | Debt export | | Debt/GDP | | Interest exports | | Arrears | |
|---|---|---|---|---|---|---|---|---|---|
| | 1988[b] | 1981 | 1988[b] | 1981 | 1988 | 1981 | 1988[b] | 1987 | Sept.1988 |
| **Latin America** | 401.4 | 247 | 339 | 46 | 53 | 28 | 28 | x | x |
| **Oil-exporters** | 159.2 | 220 | 343 | ... | ... | 23 | 28 | x | x |
| Bolivia | 3.9 | 348 | 595 | ... | – | 35 | 35 | x | x |
| Ecuador | 10.5 | 202 | 388 | 51 | 80 | 23 | 33 | x | x |
| Mexico | 96.7 | 259 | 339 | 52 | 62 | 29 | 29 | - | - |
| Peru | 16.2 | 239 | 442 | 45 | 70 | 24 | 22 | x | x |
| Venezuela | 31.9 | 160 | 290 | 56 | 49 | 13 | 26 | - | - |
| **Non-oil-exporters** | 242.1 | 273 | 337 | ... | ... | 34 | 28 | x | x |
| Argentina | 56.8 | 329 | 541 | 55 | 81 | 36 | 40 | - | x |
| Brazil | 114.6 | 313 | 321 | 39 | 42 | 40 | 30 | x | - |
| Colombia | 15.9 | 199 | 218 | 24 | 33 | 22 | 21 | - | - |
| Costa Rica | 4.1 | 229 | 260 | 90 | 108 | 28 | 20 | x | x |
| Chile | 19.1 | 311 | 236 | 73 | 74 | 39 | 23 | - | - |
| Cuba | (5.7)[c] | ... | ... | ... | ... | ... | ... | x | x |
| El Salvador | 1.9 | 174 | 185 | ... | ... | 8 | 10 | - | - |
| Guatemala | 2.8 | 96 | 225 | ... | ... | 8 | 13 | x | x |
| Haiti | 0.8 | 155 | 276 | ... | ... | 3 | 7 | ... | x |
| Honduras | 3.2 | 180 | 290 | ... | ... | 14 | 14 | x | x |
| Nicaragua | 6.7 | 464 | 2 068 | ... | ... | 37 | 103 | x | x |
| Panama | 4.2 | 92 | ... | ... | ... | ... | ... | - | x |
| Paraguay | 2.2 | 171 | 324 | ... | ... | 15 | 12 | x | x |
| Dominican Republic | 3.8 | 168 | 220 | ... | ... | 19 | 13 | x | x |
| Uruguay | 6.1 | 183 | 354 | 51 | 97 | 13 | 23 | - | - |

*Source:* ECLAC, Economic Development Division.

[a] Billions of dollars.

[b] ECLAC, *Preliminary Overview of the Latin American Economy, 1988* (LC/G.1536), Santiago, Chile, January 1989.

[c] Excluded from totals. Represents debt with so-called market countries in 1987.

**Source: Robert Devlin Options for tackling the external debt problem**
**CEPAL REVIEW No. 37/April 1989.**

Table 2 displays indicators of indebtness of selected ESCAP region economies between 1980 and 1986. One consequence of the decline or stagnation of official aid flows to the ESCAP region in the decade leading to the mid-1980's, was the rapid expansion in commercial debt. Although the Republic of Korea was the biggest debtor in the region, large current account surpluses since 1986 enabled it to make large reductions in external debt. On the other hand, India's debt to export ratio rose from 157% in 1980 to 276% in 1986 while the debt service ratio doubled to 18%. Similar trends are also visible for a number of the least developed economies in the region. Other major debtors include China, Indonesia, the Philippines and Thailand, with varying severity and capacity to ameliorate the rise of the relevant debt ratios in the last few years.

Table 2.1 shows trends in debt burden indicators for Latin America in the 80's. In 1988 the region's debt to export ratio stood at 339%, about 60% higher than in 1980, while the interest/exports ratio fell to 28%.

The net outflow of large amounts of foreign-exchange earnings to meet external debt obligations has had serious repercussions on domestic investment, growth and import capacity for many developing economies in the 1980's. Declines in per capita incomes have combined with reduced expenditures on education and social programmes and an inability to maintain a deteriorating infrastructure and industrial capacity. Despite efforts in recent years aimed at rescheduling and refinancing of debts, little has been achieved in ameliorating the continuing and growing debt levels and debt servicing obligations. Measures on debt relief or debt reduction together with availability of low cost external finance are therefore critical to many debtor developing economies in the short- to medium-run. Nevertheless a long term solution must involve, crucially, a restructuring and diversification of the commodity export sector together with improved market access and trade liberalisation measures in IAC's and other regions.

Given the persistent importance of primary commodity production and trade to several developing country groups, such as (overlapping of course) SSA, the 42 least-developed-economies, and the 66 African-Caribbean-Pacific Group of States in the Lomé Conventions, efforts to strengthen their presence in, and improve the functioning of existing commodity markets, and increase the value-added before exports are indeed relevant in the short- to medium-run. Nevertheless, a central message of this paper is that solutions to the endemic problems faced by the commodity sector and associated indebtness of developing economies must take into account the fast changing materials and manufacturing scene. For, the survival and trade prospects of many such economies in the 1990's depend on the availability and adequate provision of funds for increased education and training expenditures, the upgrading of scientific, technological, engineering capabilities and infrastructure and productive investment which meet the requirements of new and improved traditional materials production and use.

### 3.1.2 The need to reassess commodity strategies in the 1990's

As we enter the 1990's, developing economies face a pressing need for a re-evaluation of traditional strategies on commodities, including downstream processing and commodity metal and chemical production for the world market, which remain steeped in the circumstances and experiences of the post-war period and, more recently, the historically limited but impressive successes of the 1970's. Throughout the 1980's there has been a prevalent tendency for knowledge intensity in production to increase in qualitative jumps, and, the global intensification of competition and rapidity of technical change has resulted in accelerating product and process obsolescence, faster product renewal and a significant reorientation of marketing strategies. Accompanying the slow shifts in industrial structures is the spread of rapidly evolving information technologies in the production base leading, on the one hand, to a shrinkage of minimum efficient scale and erosion of barriers

TABLE 2.2

## RAW MATERIAL OUTPUT PROCESSED IN PRINCIPAL DEVELOPING COUNTRIES FOR SELECTED MINERAL COMMODITIES, AVERAGES: 1980-82, 1986-87.

(Thousand MT)

| COMMODITY / COUNTRY | 1980 - 1982 | | | | 1986 - 1987 | | | |
|---|---|---|---|---|---|---|---|---|
| | Primary production | Processed output | | | Primary production | Processed output | | |
| | | 1st Stage | 2nd Stage | 3rd Stage | | 1st Stage | 2nd Stage | 3rd Stage |
| ALUMINIUM (Al content) a | | | | | | | | |
| *Developing Countries* | *9614.3* | *3264.7* | *1932.2* | *1564.5* | *9760.3* | *4032.0* | *3062.9* | *2385.1* |
| Guyana | 554.4 | 87.8 | | | 619.3 | | | |
| Guinea | 2956.3 | 327.5 | | | 3576.5 | 278.5 | | |
| Jamaica | 2440.1 | 1117.2 | | | 1651.7 | 798.8 | | |
| Brazil | 853.5 | 260.8 | 272.0 | 280.0 | 1301.3 | 663.5 | 800.4 | 427.0 |
| Yugoslavia | 770.9 | 527.6 | 164.7 | 165.4 | 785.1 | 557.3 | 304.6 | 157.1 |
| Suriname | 805.9 | 623.5 | 46.0 | | 631.2 | 708.5 | 15.3 | |
| India | 372.9 | 244.7 | 202.6 | 234.4 | 544.1 | 309.0 | 261.2 | 318.0 |
| Indonesia | 210.4 | | | 23.1 | 128.5 | | 210.1 | 39.7 |
| Ghana | 35.4 | | 184.1 | 6.0 | 46.0 | | 137.4 | 6.4 |
| Venezuela | | | 305.0 | 71.0 | | 657.3 | 430.4 | 140.0 |
| Bahrain | | | 142.3 | 16.4 | | | 179.2 | 55.5 |
| Egypt | | | 134.3 | 49.3 | | | 178.0 | 67.5 |
| Argentina | | | 135.8 | 58.3 | | | 152.8 | 131.6 |
| United Arab Emirates | | | 96.8 | 7.2 | | | 155.3 | 8.5 |
| Korea, Rep. | | | 16.8 | 89.4 | | | 19.5 | 202.3 |
| COPPER (Cu content) a | | | | | | | | |
| *Developing Countries* | *3705.2* | *2769.0* | *2232.7* | *968.3* | *4006.1* | *3254.3* | *2800.2* | *1405.3* |
| Papua New Guinea | 160.7 | | | | 198.1 | | | |
| Chile | 1205.3 | 984.6 | 812.9 | 36.2 | 1408.6 | 1118.8 | 950.1 | 42.1 |
| Zambia | 583.4 | 587.2 | 586.0 | 2.3 | 535.3 | 518.6 | 496.6 | 8.2 |
| Zaire | 489.1 | 453.4 | 156.8 | 2.6 | 501.3 | 474.0 | 213.9 | 2.3 |
| Peru | 350.2 | 324.7 | 216.1 | 19.9 | 396.4 | 312.3 | 225.8 | 35.6 |
| Philippines | 300.6 | | | 4.2 | 218.7 | 125.1 | 134.6 | 10.0 |
| Mexico | 215.0 | 76.6 | 83.6 | 114.3 | 214.8 | 80.1 | 100.9 | 91.9 |
| Yugoslavia | 115.7 | 90.1 | 130.3 | 134.4 | 114.3 | 115.3 | 139.6 | 131.1 |
| India | 25.6 | 29.0 | 24.4 | 78.5 | 51.6 | 36.1 | 34.3 | 112.8 |
| Brazil | 12.9 | | 37.0 | 223.3 | 37.1 | 125.0 | 161.5 | 256.9 |
| Turkey | 29.0 | 22.9 | 25.1 | 33.1 | 22.5 | 27.4 | 73.3 | 73.0 |
| Korea rep. | 2.1 | 97.3 | 100.6 | 120.2 | 1.7 | 144.8 | 163.8 | 260.7 |
| IRON (Fe content) a | | | | | | | | |
| *Developing Countries* | *134732.7* | *43862.7* | *66364.3* | *n.a.* | *164580.0* | *61323.0* | *94688.0* | *n.a.* |
| Liberia | 11343.7 | | | | 9383.0 | | | |
| Brazil | 61486.7 | 11690.0 | 13513.7 | | 83969.5 | 18453.5 | 21726.0 | |
| India | 25670.3 | 9208.0 | 10431.3 | | 32320.0 | 10717.0 | 12647.5 | |
| Venezuela | 9280.7 | 372.7 | 2126.3 | | 10304.5 | 464.0 | 3368.5 | |
| Mexico | 4073.7 | 3668.0 | 7243.3 | | 5080.0 | 3710.0 | 7433.5 | |
| Chile | 5126.7 | 560.3 | 612.0 | | 4081.0 | 602.5 | 709.0 | |
| Peru | 3921.0 | 232.3 | 361.6 | | 3519.5 | 197.5 | 455.5 | |
| Turkey | 1603.3 | 2069.7 | 2714.7 | | 2873.0 | 3900.5 | 6485.5 | |
| Yugoslavia | 1665.3 | 2648.0 | 3820.0 | | 2016.0 | 2965.0 | 4443.0 | |
| Argentina | 358.3 | 984.7 | 2704.3 | | 407.5 | 1707.0 | 3422.5 | |
| Korea rep. | 284.7 | 7314.0 | 10353.7 | | 291.5 | 10039.5 | 15066.5 | |
| Mauritania | 5551.3 | | 10.0 | | 5974.0 | | 6.0 | |
| TIN (Sn content) a | | | | | | | | |
| *Developing Countries* | *178.3* | *167.1* | *23.5* | *n.a.* | *121.2* | *125.8* | *36.2* | *n.a.* |
| Malaysia | 37.9 | 65.1 | 0.4 | | 29.7 | 44.1 | 1.9 | |
| Brazil | 7.8 | 8.6 | 4.3 | | 28.1 | 28.3 | 6.9 | |
| Indonesia | 33.9 | 30.9 | 0.4 | | 25.4 | 23.1 | 1.0 | |
| Thailand | 30.5 | 30.9 | 0.7 | | 15.8 | 17.5 | 1.7 | |
| Bolivia | 27.9 | 18.8 | 1.2 | | 9.3 | 5.2 | 1.1 | |
| Korea rep. | | 0.3 | 2.0 | | | 1.5 | 4.1 | |
| India | | | 2.4 | | | | 2.7 | |
| Yugoslavia | | | 1.0 | | | | 1.5 | |
| NICKEL (Ni content) a | | | | | | | | |
| *Developing Countries* | *247.6* | *106.0* | *35.6* | *n.a.* | *263.5* | *142.8* | *69.2* | *n.a.* |
| Philippines | 27.9 | 17.8 | | | 10.4 | | | |
| Botswana | 17.2 | | | | 17.8 | | | |
| Indonesia | 44.8 | 4.7 | | | 62.2 | 3.8 | | |
| New Caledonia | 74.9 | 29.5 | | | 61.6 | 31.3 | | |
| Cuba | 38.7 | 20.6 | | | 37.5 | 18.4 | | |
| Dominican Rep. | 15.2 | 15.2 | | | 27.2 | 27.1 | | |
| Colombia | | | | | 19.1 | 19.1 | | |
| Brazil | 8.1 | 3.2 | 9.4 | | 13.4 | 13.4 | 14.0 | |
| Zimbabwe | 14.3 | 14.0 | | | 10.6 | 16.5 | | |
| Yugoslavia | 2.0 | | 1.9 | | 3.3 | 3.3 | 3.0 | |
| Korea Rep. | | | 3.2 | | | | 6.0 | |
| Mexico | | | 3.8 | | | | 3.4 | |

Source: Part III UNCTAD Commodity Yearbook.

Note: a. Primary production and processed products by individual commodity are shown in the table below :

| Commodity | | Primary production | 1st stage of processing | 2nd stage of processing | 3rd stage of processing |
|---|---|---|---|---|---|
| Aluminium | : | Bauxite, | Alumina, | Aluminium refined, | Refined aluminium consumption. |
| Copper | : | Copper ore, | Blister Copper, | Refined Copper, | Refined copper comnsumption. |
| Iron | : | Iron ore, | Pig Iron, | Crude steel, | |
| Tin | : | Tin ore, | Tin metal, | Primary tin metal consumption. | |
| Nickel | : | Nickel ore, | Refined Nickel, | Refined Nickel consumption. | |

to entry in some sectors, and, on the other hand, the erection of greater barriers and enlargement of scale economies in others, due to learning by doing vast scientific content of production and large research expenditures required.

As if coming to grips with such difficulties was not enough, the trends and tendencies identified in this paper as emanating from the revolution in materials science and engineering further complicate matters and usher in new unknowns and imperatives. Primary producing developing economies are no longer inserted in the world division of labour on the basis of large scale commodity provision to the needs of mass-production and mass consumption in IAC's. Rather, they find themselves enmeshed in a world economy undergoing fundamental restructuring and transition to post-Fordist methods of production, and patterns of consumption in the context of an emerging new socioeconomic and technological paradigm, embracing the triad of information, materials and bio-technologies. In this transition, the role of new, improved traditional and advanced materials has been, and unquestionably will continue to be highly significant. As demand patterns, resource requirements and processing facilities are reordered and shifted internationally, so will, therefore, change the role and importance of traditional suppliers of raw and semi-processed mineral and agricultural raw materials. The issues, though are broader, and go far deeper, than the mere evaluation of Third World prospects in terms of future demand projections for traditional ores, commodity metals or agricultural products.

Not only is it exceedingly prudent for developing economies to ask whether it is feasible and advisable to remain in specific commodity production as a long-run proposition, but also to reassess the wisdom and the conditions under which they should remain or enter downstream processing in the 1990's. Whether an economy is to remain or exit from a specific commodity, the fact remains that it still has to establish an institutional and manufacturing base that can survive and prosper in the scientific, technological and global market conditions of the 1990's. The central point is that the materials sector is now steeped in new scientific and engineering capabilities, with new best practice technologies that can be directed to meet basic needs more efficiently, and/or meet the quality, reliability, and low cost reproduction requirements at all stages of processing and semifabrication demanded by materials and components users. The acquisition of the attendant engineering, scientific, educational, testing and quality control, and infrastructural capabilities thus becomes a vital concern for developing economies, attempting to meet materials for small scale industry embracing flexible specialisation or flexible mass manufacturing, producing locally or sourcing globally. Hence materials issues and strategies are inseparable from the process of the global restructuring of industry and the evolving conditions for the location of labour- and skill-intensive activities across manufacturing. It is to this we now turn.

## 3.2 The restructuring of industry in the period 1970's-1980's

### 3.2.1 Restructuring of industry within IAC's and redeployment to LDC regions in the 1970's

Since the 1960's, progress has been made (See Table 2.2.) in the processing before export of domestically produced agricultural and mineral raw materials in developing countries, in part of a deliberate result of a resource based industrialisation strategy. The higher degree and greater global share of processing activities undertaken in LDC's has, of course, also resulted from underlying economic forces. Declining ore quality, escalating energy prices, increased environmental regulations and compliance costs, and higher labour costs in the 1970's in IAC's meant that energy-rich, resource-rich developing regions (together with Canada and Australia in some minerals) became increasingly attractive for replacement and expansion of capacity as the location of smelting capacity in IAC's was rendered increasingly uneconomic. This has also been the case for petrochemicals, synthetic fibres and other energy intensive basic industries. This is not the place for a detailed sectoral examination of the trends in organic and inorganic minerals processing capacity within OECD economies since the early 1970's. Suffice it though to point out that this process whereby declining sectors in the industrial structures of IAC's in labour-intensive or energy and raw material intensive activities began to be restructured and redeployed to LDC's in the 1970's, was welcome by UNIDO as broadly in line with changing patterns of comparative advantage in the context of the internationalisation of production. Increasing domestic raw material capacity in LDC's in erase line with long-run development objectives together with the redeployment of processing industries and labour intensive branches, such as textiles, shoes etc, to LDC's was viewed by UNIDO as part of converging interests of LDC's, MNC's and governments in IAC's. Moreover, such global industrial restructuring and redeployment was part of the process of increasing the share of LDC's in global manufacturing to 25% by 2000, as the Lima declaration envisaged. Nevertheless this happy coincidence of interests accompanying a frictionless restructuring and redeployment of industries from IAC's to LDC's soon faced difficulties. Over capacity appeared in several sectors in the early 1980's, there were growing voices of concern over import penetration of manufactures from NIC's and protectionist barriers began to be erected to protect IAC's basic industries facing severe difficulties. The restructuring of industry in the 1980's introduced new unknowns into the process of global redivision of labour and the expulsion of basic and declining branches from IAC's.

### 3.2.2 The diffusion of microelectronics-based automation technologies in the 80's.

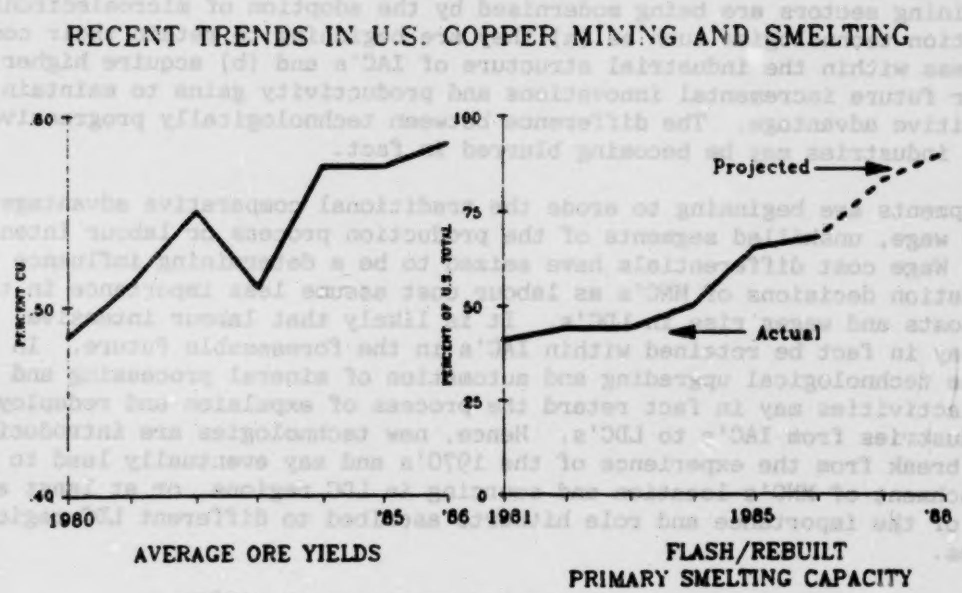
The industrial structure of IAC's is shifting towards high growth, high technology, knowledge intensive branches of industry with large intersectoral linkages to the rest of the economy. Mass production and batch-production industries within the capital goods and engineering sectors are automating and reorganising their production lines with the incorporation of flexible manufacturing techniques. Mature, declining sectors are being modernised by the adoption of microelectronics based automation technologies such as (a) they are beginning to retain their cost competitiveness within the industrial structure of IAC's and (b) acquire higher potential for future incremental innovations and productivity gains to maintain their competitive advantage. The difference between technologically progressive and stagnant industries may be becoming blurred in fact.

These developments are beginning to erode the traditional comparative advantage of LDC's in low wage, unskilled segments of the production process or labour intensive industries. Wage cost differentials have seized to be a determining influence in offshore location decisions of MNC's as labour cost assume less importance in total production costs and wages rise in LDC's. It is likely that labour intensive activities may in fact be retained within IAC's in the foreseeable future. In addition, the technological upgrading and automation of mineral processing and fabricating activities may in fact retard the process of expulsion and redeployment of basic industries from IAC's to LDC's. Hence, new technologies are introducing a fundamental break from the experience of the 1970's and may eventually lead to a major retrenchment of MNC's location and sourcing in LDC regions, or at least a realignment of the importance and role hitherto ascribed to different LDC regions and countries.

### 3.2.3 The restructuring of basic materials industries in the 1980's.

Looking at the restructuring process of basic industrial branches within the industrial structure of IAC's in the 1980's, a number of interesting tendencies can be identified. Large segments of outdated and inefficient productive capacity have been shut down, while remaining capacity has been modernised and technologically upgraded (see Diagram 3). This technological renewal and rejuvenation of traditional smelting and processing capacity has resulted in a smaller but more efficient and competitive capacity, exemplified by the current healthy state of US copper and primary aluminium industries. Although retaining a certain portion of domestic capacity in traditional 'smoke-stack' industries is deemed desirable, a consensus seems to be emerging that economic, and political, pressures are making for an inexorable march of commodity metal and petrochemical production to developing regions, and Australia and Canada, from which the requirements of IAC's are to be met on the principle of least cost sourcing. At the same time, as commodity metal and chemicals production is being relinquished and/or relocated abroad, firms in these industries have began a discernible strategic move downstream, into high-value added processing and fabrication of specialty metals and chemicals aimed at specific market niches. This of course is in line with the tendencies of the transition to post-Fordist industrial organisation as it permeates and appropriates the production of intermediates entering into final goods. A related feature of these ongoing processes is the forging of close relationships between metals, chemicals, ceramics and glass producers and their customers in industry, with the aims of meeting the latters' more stringent specifications and property requirements in specific applications, thus also fending off competition from competing materials of course. Together with the move to downstream vertical integration, a number of firms in Japan, Europe and the USA, have began to diversify into related business, and into advanced materials, with varying degrees of success. In fact, the tendency towards the in house acquisition of the multi-disciplinary scientific and engineering capabilities for a multi-materials competence in conditions in which barriers between traditional materials markets are eroding, marked by significant interpenetration of materials in end-uses, is a major feature of the current transition. Accompanying the transition towards diversification and entry into new material competences is the tendency to form joint ventures and technology licensing agreements, together with mergers and acquisitions, across national boundaries in virtually all new materials.

Diagram 3: Recent Trends in U.S. Copper Mining and Smelting

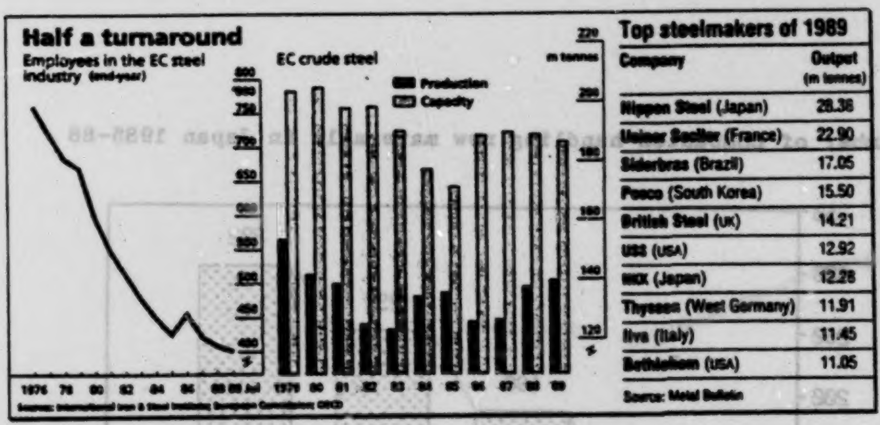


Source: L.J. Sousa, Problems and Opportunities in Metals and Materials, U.S. Bureau of Mines, 1989.

In the European Community's (EC) steel industry the labour force has been halved since 1976 (See Diagram 3.1), and over 30m. tonnes of steel capacity was shut between 1980-86. Nevertheless, there is still an annual excess capacity of 47m. tonnes within the EC, which implies that the painful restructuring of the 80's is not at an end. At the same time, Europe's steel producers have improved productivity and have began to forge closer links with users in industry, such that over two thirds of EC steel is tailor-made to customer needs. Car manufacturers, for example, now demand flawless materials for just-in-time delivery and production. Hence steelmakers must closely cooperate with industrial users to develop the highest quality materials and processing technologies to meet customer specifications in end products. Commodity steel products such as heavy plate and wire rod are being relinquished, as EC steel producers, in common with their American and Japanese counterparts, are moving to higher value added and more specialised products, such as higher grade carbon steels, stainless steel, galvanised sheets and high-tech specialties.

In Japan, the largest five steelmakers (Nippon Steel, Nippon Kokan, Kawasaki Steel, Sumitomo Metal Industries and Kobe Steel) are aiming to shut down 8 of Japan's 34 blast furnaces by 1990. The industry as a whole has been automating and cutting capacity, such that the labour force has been reduced by 47,000 since 1986, to a remaining total of just under 300,000. The pronounced move to higher margin products and specialties by Japanese steelmakers, together with the expected mastering of new mini-mill specialty technologies by other firms in the region, such as South Koreas Pohang Iron and the Taiwan Province's Anfang and Yie United, signify an impending export drive to western markets and an intensification of competitive pressures. European producers are bracing themselves against this looming threat and have began to adopt defensive measures through cross border mergers, acquisitions and joint ventures.

Diagram 3.1: EC Steel Industry Trends



Top steelmakers of 1989

| Company | Output (m tonnes) |
|---|---|
| Nippon Steel (Japan) | 28.36 |
| Usinor Sacilor (France) | 22.90 |
| Siderbras (Brazil) | 17.05 |
| Posco (South Korea) | 15.50 |
| British Steel (UK) | 14.21 |
| USS (USA) | 12.92 |
| NKK (Japan) | 12.28 |
| Thyssen (West Germany) | 11.91 |
| Ilva (Italy) | 11.45 |
| Bethlehem (USA) | 11.05 |

Source: Metal Bulletin

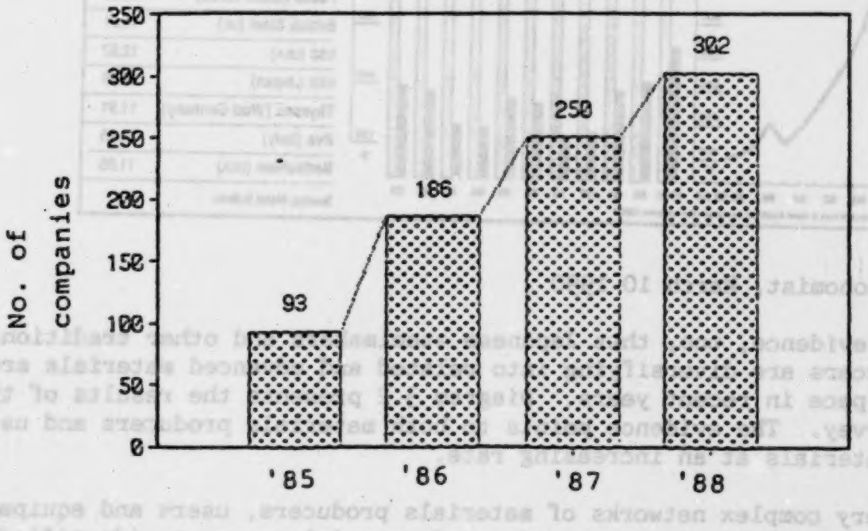
Source: The Economist, March 10 1990

There is clear evidence, too, that Japanese steelmakers and other traditional materials producers are diversifying into related and advanced materials areas at an accelerated pace in recent years. Diagram 3.2 presents the results of the latest MITI survey. The evidence points to both materials producers and users entering new materials at an increasing rate.

In addition, very complex networks of materials producers, users and equipment makers have come into being in those advanced materials segments identified as offering the greatest technological and market growth potential, namely fine ceramics, carbon fibres, engineering plastics and amorphous metals. The figure below shows a typical example of just such an industrial network in fine ceramics, Diagram 3.2: Entry into new materials by industry, Japan 1985-88

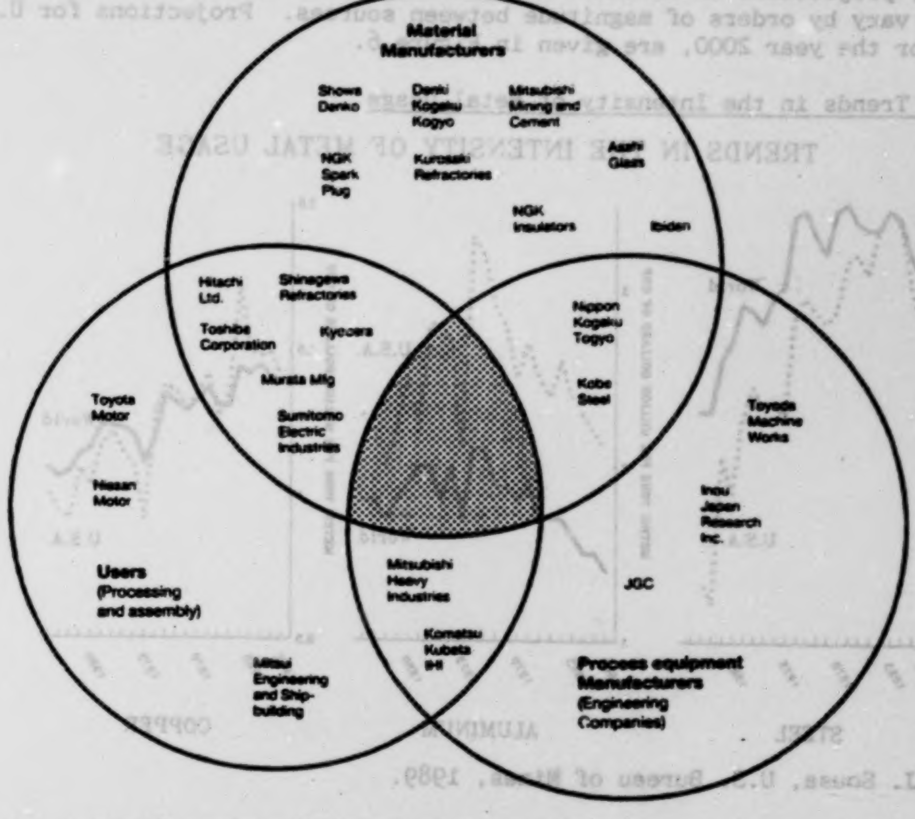
| | 1985 | 1988 | '88/'85 |
|---|---|---|---|
| Chemicals | 33 | 67 | 2.0 |
| Glass/Ceramics | 12 | 35 | 2.9 |
| Nonferrous metals | 11 | 27 | 2.5 |
| Steel | 15 | 24 | 1.4 |
| Textile | 7 | 20 | 2.9 |
| Petroleum/Rubber | 5 | 12 | 2.4 |
| Pulp/Paper | 2 | 9 | 4.5 |
| Producers subtotal | 85 | 194 | 2.3 |
| General machinery | 0 | 20 | --- |
| Electric machinery | 5 | 18 | 3.6 |
| Transportation machinery | 3 | 13 | 4.3 |
| Precision machinery | 0 | 11 | --- |
| Construction | 0 | 4 | --- |
| Users subtotal | 8 | 66 | 8.3 |
| Others | 0 | 42 | --- |
| Total | 93 | 302 | 3.2 |

**Number of companies handling new materails in Japan 1985-88**



which not only reflects the greater need for closer links between producers and users, but also greatly facilitates the speedy and efficient development and commercialisation of a new materials technology. This, coupled with the emerging close ties between the relevant government agencies, universities and firms in the materials field, confer unique competitive advantages to Japanese industry in the development and fast commercial application of new materials.

Figure 5.1: Typical Examples of Materials Manufacturers, Users and Process Equipment Manufacturers Participating in Fine Ceramics Industry


Material Manufacturers
Showa Denko
Denki Kogaku Kogyo
Mitsubishi Mining and Cement
NGK Spark Plug
Kurosaki Refractories
Asahi Glass
NGK Insulators
Ibiden
Hitachi Ltd.
Shinagawa Refractories
Toshiba Corporation
Kyocera
Murata Mfg
Sumitomo Electric Industries
Nippon Kogaku Togyo
Kobe Steel
Toyota Motor
Nissan Motor
Toyoda Machine Works
Inou Japan Research Inc.
Users (Processing and assembly)
Mitsubishi Heavy Industries
JGC
Komatsu Kubota IHI
Mitsui Engineering and Ship-building
Process equipment Manufacturers (Engineering Companies)

Source: Industrial Research Division, The Long-term Credit Bank of Japan Ltd.

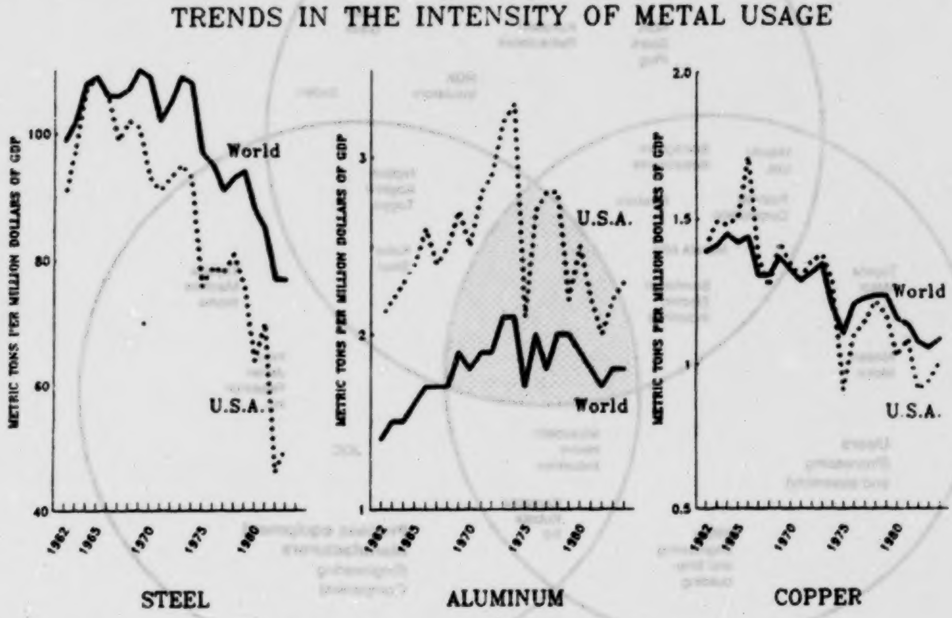
In: OECD Advanced Materials, Paris, April 1990.

National and international commodity policy is therefore necessarily enmeshed in these structural transformations of the materials producing sectors, the emerging business strategies influencing global location and sourcing, and the impact of new technologies and organisational change on the materials processing and fabrication stages themselves as well as on the materials using industries.

### 3.2.4 Traditional versus advanced materials

The restructuring process of the IAC's is also reflected in the interplay between the use of (improved) traditional and advanced materials in industry. Although the adverse impact of substitution and technical change is not a new phenomenon for industrial raw materials, the observed marked declines in intensity of use since the early 1970's may signal the outset of irreversible and structural forces acting on the demand side. Sectoral shifts in the product composition of national output away from materials intensive sectors, and declining material ore per unit of final output, which is the result of substitution and technological and organisational change in manufacturing, have combined to reduce intensity of use. This process may continue in the 1990's and indeed accelerate as a wide range of natural fibres, sugar and metals such as aluminium, steel and copper face greater substitution from the diffusion of advanced materials, especially engineering polymers. Attempting to quantify the impact of advanced materials on traditional materials in the 70's and 80's, comes up against insuperable data availability difficulties which have yet to be overcome. At the same time attaching specific numbers to future projections on specific commodities and advanced materials is fraught with difficulties and ambivalent trends in the underlying factors. Although advanced materials and minor metals are expected to display very high growth rates over the next decade, projections on advanced materials are nothing more than informed guesses and vary by orders of magnitude between sources. Projections for U.S.A. and Japan for the year 2000, are given in Figure 6.

Diagram 4: Trends in the Intensity of Metal Usage

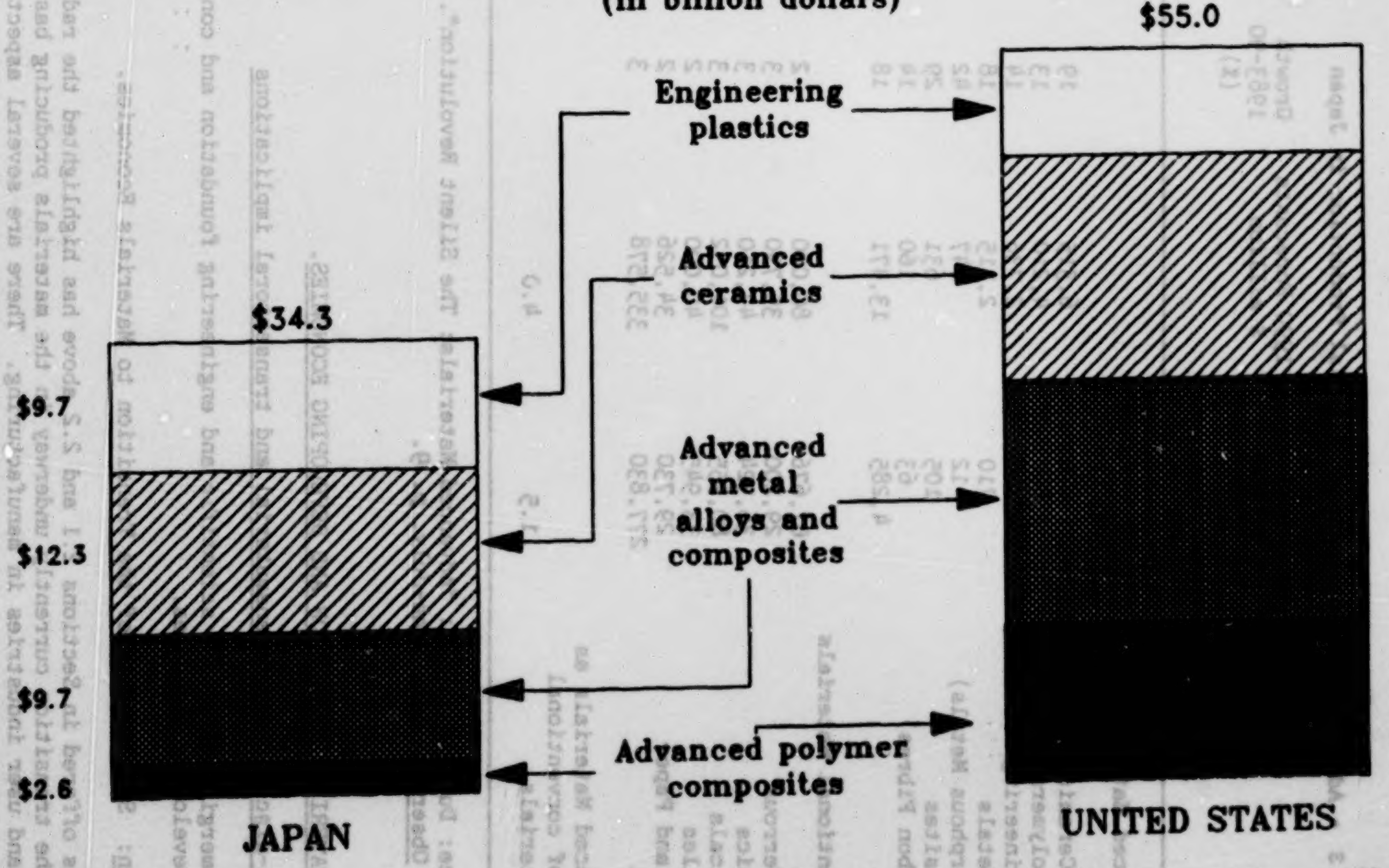


Source: L.J. Sousa, U.S. Bureau of Mines, 1989.

Thus, trends in intensity of use and demand for specific raw and semi-processed commodities in the 90's and beyond depend on the complex interplay between a number of factors: the growth of economic activity in developed and developing economies; sectoral growth rates and the formation of fixed capital; the evolution of consumer tastes and environmental concerns; technical change and potential further economisation in material use; defensive R & D and marketing in many commodities utilising the insights of MSE (eg. natural rubber, cotton, wool, aluminium, steel, nickel, zinc); and the degree of market penetration by advanced materials in the 1990's. The competition between traditional but greatly improved materials and advanced materials will intensify in the next few years and the outcome cannot be predicted. Existing materials can of course form an alliance with advanced materials in matrix composites, while one material is unlikely to displace another wholesale given the preference of manufacturers to employ diverse materials in synergistic combinations in complex systems such as aircraft or cars. Apart from processing, cost, reproducibility, awareness, inertia and sunk capital constraints in the diffusion of advanced materials, the latter are currently creating new uses rather than displacing traditional materials from existing applications. Hence the diffusion and substitution process is likely to be prolonged and uncertain as to outcome. The fact remains that such materials are critical in high technology sectors, they will become even more important in the future, and a massive research

**Figure 6:** ADVANCED MATERIALS: FORECAST MARKETS IN THE UNITED STATES AND JAPAN IN THE YEAR 2000

(in billion dollars)



*Includes fiber optics.

**Includes specialty metals.

Source: L.J. Sousa, US Bureau of Mines, 1988 effort is underway to resolve the processing constraint. Hence there is no room for complacency in developing regions, especially given the large gains of early entry in production and use.

Some indication of the relative importance of advanced materials in comparison to traditional materials is provided in the table 3 below for the case of Japan:

**Table 3 - Advanced and Conventional Material Production in Japan**

| | 1983 $ million | 1990 Forecasts $ million | Growth 1983-90 (%) |
|---|---|---|---|
| **Advanced Materials** | | | |
| Fine Ceramics | 1,670 | 6,315 | 19 |
| New Polymers | 1,800 | 4,210 | 13 |
| (Engineering Plastics) | 1,100 | 2,736 | 14 |
| New Metals | 710 | 2,315 | 18 |
| (Amorphous Metals) | 12 | 147 | 42 |
| Composites | 105 | 631 | 29 |
| (Carbon Fibres) | 63 | 160 | 14 |
| Total | 4,285 | 13,471 | 18 |
| **Conventional Materials** | | | |
| Steel | 67,676 | 80,000 | 2 |
| Non-ferrous | 29,200 | 35,790 | 3 |
| Ceramics | 36,324 | 44,210 | 3 |
| Chemicals | 80,955 | 101,052 | 3 |
| Textiles | 33,945 | 40,000 | 2 |
| Pulp and Paper | 29,730 | 34,526 | 2 |
| Total | 277,830 | 335,578 | 3 |
| **Advanced Materials as % of conventional materials** | 1.5 | 4.0 | |

Source: Dubarle (1989): "Advanced Materials: The Silent Revolution". OECD Observer, 158, June-July, p. 9.

## 4. THE MATERIALS REVOLUTION AND DEVELOPING ECONOMIES.

### 4.1 Multi-disciplinary, transmaterial and transectoral implications

### 4.1.1 The emerging materials scientific and engineering foundation and consequences for developing economies.

Introduction: Some Aspects of the Transition to Materials Economies.

The analysis offered in Sections 2.1 and 2.2 above has highlighted the radical nature of the transition currently underway in the materials producing basic industries and user industries in manufacturing. There are several aspects to this transition, which necessitate that materials issues be viewed in a multi-, or at least inter-, disciplinary, and transmaterial context.

Approaching materials research and development armed with a deep understanding of the linkages between the structure and composition, properties, synthesis and processing and performance of a material, highlights a common scientific and engineering base across the materials spectrum. The trend in modern science towards an examination of elementary particles, atoms, and molecules cuts across materials whatever their origin, and indeed crosses over and embraces other fields such as biotechnologies and genetic engineering of living organisms.

The scientific base is closely integrated to the engineering and processing stage, and the complexity of the issues requires the cooperative involvement of a multitude of disciplines and specialised individuals and research teams within and between scientific and engineering disciplines. Although traditional delineations between disciplines are beginning to erode, specialisation still occurs, so that, at the very least, cooperation across disciplines and individuals is required at this stage, before a fully-fledged multi-disciplinary competence emerges. MSE departments are beginning to train a new generation of materials scientists and engineers across the various fields of science and materials, but several years will elapse before current practices are superseded. Nevertheless, what is clear is that new materials development involves multi-disciplinary competences and synergies across diverse fields.

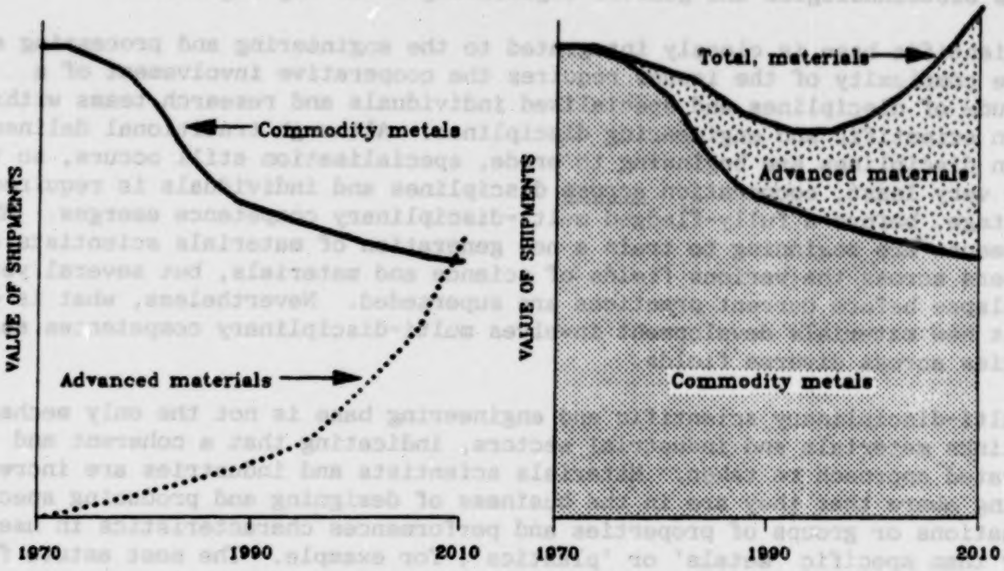
The multi-disciplinary scientific and engineering base is not the only mechanism that links materials and industrial sectors, indicating that a coherent and integrated approach be taken. Materials scientists and industries are increasingly becoming aware that they are in the business of designing and producing specific combinations or groups of properties and performances characteristics in use, rather than specific 'metals' or 'plastics', for example. The most astute firms are therefore in the process of transforming themselves from being, say, a specialised aluminium company to a corporation with multi-materials competences. Materials producers need to become acquainted with the design and production of several materials and with the specifications and property requirements of their customers in end-uses. Viewing this from the angle of the materials users, it means that the latter increasingly need to be acquainted with scientific and processing aspect of new materials development and use, the variety of materials available and the potential for developing materials tailor-made for new product designs. Hence issues here are beginning to acquire both a transmaterial and transectoral nature, both within and between producing and using sectors.

Throughout the 1970's and 1980's we have been witnessing a slow transition of IAC's from being primarily metals based economies toward 'materials economies'. Basic industries are restructuring such that industries and firms specialising in monolithic materials and relatively undifferentiated product structure, are giving way to multi-material firms with a large range of differentiated, high-value added, knowledge intensive products. Boundaries between traditional materials in terms of relatively well defined and 'safe' markets are eroding, with significant interpenetration of materials across uses. This is another way of viewing the fact that traditional monolithic materials have seized to constrain and dictate the design of end-use products, a profound change in the functioning, innovative capacity and growth of manufacturing industry. Materials users are thereby being liberated from the constraints of a single or a range of traditional materials available to designers 'off the shelf'. Greater materials variety is coupled with the potential to engineer materials tailor made for new designs, thus ushering in a period of vastly enhanced design capabilities and flexibility throughout manufacturing.

A visual guide to the nature of the transition of industrialised economies from a primarily commodity metals base towards the increasing diffusion of advanced materials in the context of the restructuring we have been describing above is shown in Diagram 4.1:

**Diagram 4.1**

**Diagram 4.1** SUMMARY: TRANSITIONING, FROM A METALS ECONOMY TO A MATERIALS ECONOMY



Source: L.J. Sousa, U.S. Bureau of Mines, 1988, op.cit.

**Clearly commodity metals are still expected to play a significant role in the economy over the next two decades, albeit with ever increasing quality and knowledge-content. But beyond this, what this transition indicates is that an all-embracing, comprehensive view is required right across the materials field if we are to understand the complex nature of the issues and identify the trends. Thus, what is becoming clear is that concentration on a specific material or industrial sector is likely to miss critical aspects and trends which permeate the whole of the materials base and govern its movement and that of its constituent parts. Mono-material and specialised approaches and institutions are a dangerous anachronism in the current transition in the materials field.**

**The acquisition of multi-disciplinary competences and the examination of issues and trends along a transmaterial and transectoral spectrum are therefore becoming a necessity at the level of the firm, the industry and the institutions of the economy at large. This is especially the case for the private and public materials related institutions, research centres, universities and industry in developing countries in the emerging new materials era. Coming to terms with these needs will require both institutional cooperation between developing countries and between developing countries and institutions and industry in IAC's. In addition, the creation of new regional and international centres for materials basic research and techno-economic analysis, which embrace the necessary multi-disciplinary and transmaterial approach would offer significant assistance to developing economies in this complex and difficult conjuncture. We comment further on this in section 4.2.1.**

## New and Improved Materials and Developing Economies

Although the radical developments in the materials field are well recognised in the scientific community, awareness of the seriousness and speed of change in this area has still not permeated the public domain. Governments[7] in the developed countries have responded to pressure from scientific and professional societies as well as high-technology sectors and have, for several years now, initiated large programmes of financial and institutional support for domestic materials pure and applied research. On the other hand, apart from few notable exceptions, both government and industry in the developing world show distinct lack of awareness of the potential impact of the new developments for domestic resources, industry and trade prospects. And, where the new scientific and technological circumstances have been identified, there is often a lack of appropriate institutional capacity to respond, and/or a feeling that such changes are too remote and operating at the frontiers of science, and, hence of not much relevance to developing economies.

It is important to stress at the outset that the revolution in materials science and engineering has an impact right across the materials spectrum, from commodity metals such as primary aluminium and copper and the creation of new advanced alloys, engineering plastics, advanced ceramics and composite systems, to agricultural commodities such natural fibres and, others such as natural rubber, wood, cotton, and cement. New advanced materials are beginning to make inroads into the markets of traditional materials, such as monolithic metals, but the latter are actually responding scientifically, technologically and in terms of marketing strategies, so that the outcome is by no means clear. In fact, advanced materials in the next century could well include specialty steels, advanced aluminium alloys, and in some respects, higher quality cement and wood.

A number of propositions follow and we briefly discuss them below:

1. Improve traditional materials and processing technologies.

   The first important point to note is that the insights of materials science and engineering as set out in 2.1 above, can be used and must be used to improve the properties and processing technologies of existing traditional materials.

   Tremendous scope exists for the improvement in the processing technologies of traditional materials and this is a point of obvious significance to developing economies whether the aim is to produce for the world or the domestic/regional markets. Even if economic and political forces are inexorably leading towards the redeployment of major portions of basic materials processing branches to developing regions, this will necessarily be accompanied by the employment of best practice advanced processing and fabricating technologies. (See also section 4.1.2 below).

   Further, given the pressures of the world market and users-industries (see 2.2) for higher quality, durability, and reliability no industry or economy can afford to ignore this, at any stage of the materials cycle. This applies to materials selection in a range of user manufacturing activities, from designer dominated, small-scale, flexibly specialised industries such as clothing, furniture and footwear to the provision of materials, components and sub-assemblies to the emerging high-tech and flexible mass production industries such as automobiles. The decision to locate in, or, source from developing economies in the 1990's will be greatly affected by the quality and reliability of the materials on offer.

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[7] International Cooperation and Competition in Materials Science and Engineering, National Institute of Standards and Technology, U.S. Department of Commerce, June, 1989.

Further, the successful efforts to improve the properties of commodities such as natural rubber, wool and cotton as compared to synthetics is a pointer to greater collaborative efforts by LDC's on a regional, and cross-commodity basis.

2. A Materials Science for Development.

The large and increasing basic needs of developing economies in housing, transportation, food packaging, water and energy distribution and health care can be met[8] through more efficient utilisation and upgrading of domestically or regionally available natural resources, using scientific insight and new and improved technologies. The materials revolution affords opportunities to developing economies to make fuller use of domestic materials, while minimising energy requirements and environmental disruption. Included in this is the development of advanced materials designed to meet needs and conditions in developing countries. That is, advanced materials must be tailored to meet needs and specific requirements of industry and infrastructure in developing countries.

We concur with Professor Rohatgi, that the new materials science and engineering base must be mobilised, internationally and within the Third World, to meet the needs of development in the coming decades. For although the science base of the new materials is common throughout the world, the direction of application and problem orientated R&D cannot exclude the pressing needs and available resources of developing economies. Examples of new materials aimed at satisfying basic needs in developing economies is given in Table 4. In so far as possible such materials should be "...small, lighter, longer lasting, low cost, low energy and recyclable based on abundant and renewable resources which can be locally processed using simple and employment generating non-polluting technologies".

In housing, MSE can examine alumino silicates, earth, stone laterite and clay based products, which are readily available, and improve brick performance. In addition, modern materials science can also focus attention on renewable resources such as plant based construction materials (e.g. bamboo, sisal, grasses, and wheat straw), and improve their performance for housing.

In the area of bio-processing of materials, advanced genetic engineering may lead to a strengthening of wood and fibres, microbiological processes can be used to extract metals, and yet other microbiological technologies can be used to extract fibres and ultrafine powders of silica from plant based materials to make advanced ceramics and composites.

Moreover, new advanced materials and inexpensive membranes and filters can be developed to purify and desalinate water, as well as meet the needs for the production, transportation and storage of food. It is worth noting that the U.S. based Alcoa corporation is currently researching into new advanced packaging materials for food and post-harvest products of great relevance to developing economies.

3. Raw Materials and Technologies for Advanced Materials.

Many developing economies possess materials and/or technology and human resource skills that are directly relevant to the production and use of new advanced materials. Hence, the evolving materials era also offers

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8 Professor Pradeep Rohatgi, Current Revolution in New Materials: Opportunities for the Developing World, Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June, 1989.

**Table 4: Some Important Targets for Materials Technology for Development**

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- Genetic engineering for plants to get nitrogen directly from air.
- Genetic engineering for plants with stronger timber and fibers which can be pyrolized to form high performance fibers and carbon-carbon composites.
- Microbial processes to extract metals from ores and ocean nodules, and to remove sulphur and silica from coal, bauxite and other minerals.
- Microbial processes to extract fibers and ultrafine ceramic particles from agricultural products and wastes.
- Solar photovoltaic materials with increasing efficiencies and decreasing costs; solar furnaces for processing materials.
- Materials for fusion energy.
- Membranes made for polymers, ceramics and composites with decreasing costs and increasing performances for purification of water.
- Improved and inexpensive materials for housing from abundant and renewable resources like sand, clay, rock, stones, laterites, plant based materials.
- Composites and ceramics with improved performances based on abundant elements like Al, Si, C, N and plant materials.
- Direct Reduction of iron and aluminum using low energy processes, using solar and biomass energy.
- Recyclable materials with cascading downgraded application with longer life and resistance to corrosion, oxidation, wear and fatigue.
- Rapidly solidified materials for reducing energy losses.
- Surface and interface processed materials with tailored structures and properties to meet specific needs.
- High performance nano-structured materials, nonequilibrium and metastable structures.
- Room temperature superconductors.
- Insitu polymer composites.
- Tough ceramics.
- Net shaped materials fabrication.
- Parts consolidation through single step molding of complex shapes.

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**Source: P. Rohatgi, 1989, op. cit.**

opportunities to developing countries, where appropriate, to gradually enter new materials production, quality control and trade at several stages of the transformation of the raw material into semi-processed and processed forms and components entering final use.

## Neodymium Supermagnets

Consider, as an example, the rare earth element neodymium[9] and its use in the new generation of permanent magnets. Neodynium belongs to the rare earth 'lanthanide' group of elements. Over 95% of existing permanent magnets are alnico or hard ferrite type magnets. Currently the highest energy product of all existing practical permanent magnets is provided by the rare earth cobalt magnets. Nevertheless there are indications that the new generation of supermagnetic materials, which have generated large international interest, as the new a rare earth magnets neodymium-iron-boron are known, could replace the ferrite, alnico and rare earth samarium-cobalt magnets.

Neodymium is derived from three main minerals, bastnasite, monazite and Xenotime and constitutes about 17%, by weight, of all rare earths mined. The main producers of rare earth minerals are to be found in the U.S.A., Australia, China, India, Malaysia, U.S.S.R., Brazil, Canada, Sri Lanka, Thailand, Zaire and Madagascar, in order of importance. Neodymium constitutes about 13% of rare earth content, and the distribution of its reserves is shown in Table 5, indicating a 100 year life. (See also Tables 5.1 and 5.2).

Table 5: Neodymium Reserves in the World

| Country | Estimated Reseserves Kg x 103 |
|---|---|
| USA | 650,000 |
| India | 400,000 |
| South Africa | 15,000 |
| Central Africa | 6,000 |
| Malaysia | 5,000 |
| Brazil | 5,000 |
| China | 4,600,00 |
| USSR | 70,000 |
| Australia | 8,000 |
| Others | 50,000 |

Source: N.C. Kothari, 1989.

Taking advantage of the opportunities offered by neodymium in magnetic, colour glass, capacitors, and laser applications and of other rare earth elements in magnetic property applications and in advanced ceramic and glass technologies will doubtless involve familiarisation with a variety of complex extractive and processing methods for rare earths, including lengthy processing routes such as metallothermic reduction, electromining and the new molten salt extraction process 'Neochem' for neodymium. In addition,

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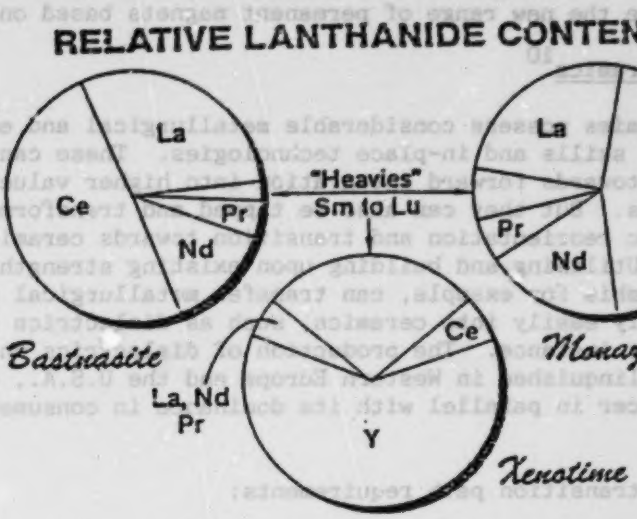
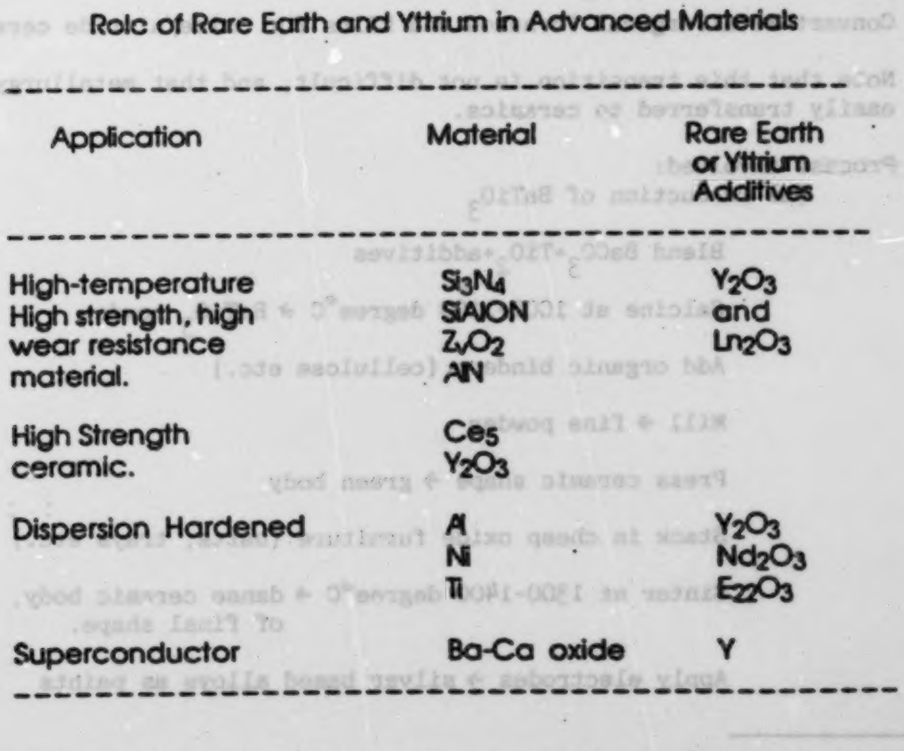
[9] N.C. Kothari 'Neodymium Supermagnet - Key Material for Tomorrow's Electrical and Electronic Industry', Minsk Workshop, 29 May - 2 May, 1989, ibid.

**Table 5.1: Relative Neodymium content of the three major minerals**



**Source:** Ibid.

**Table 5.2: Role of Rare Earths and Yttrium in Advanced Materials**



Role of Rare Earth and Yttrium in Advanced Materials

| Application | Material | Rare Earth or Yttrium Additives |
|---|---|---|
| High-temperature High strength, high wear resistance material. | $Si_3N_4$<br>SiAlON<br>$ZrO_2$<br>AlN | $Y_2O_3$<br>and<br>$Ln_2O_3$ |
| High Strength ceramic. | $Ce_5$<br>$Y_2O_3$ | |
| Dispersion Hardened | Al<br>Ni<br>Ti | $Y_2O_3$<br>$Nd_2O_3$<br>$Er_2O_3$ |
| Superconductor | Ba-Ca oxide | Y |

**Source:** Ibid

developing economies will need to employ RSP-PM (rapid solidification processing and powder metallurgy) technologies, as well as other more recent techniques, to produce the new range of permanent magnets based on neodymium.

## From metallurgy to ceramics[10]

Many developing economies possess considerable metallurgical and engineering practical experience, skills and in-place technologies. These can be judiciously directed towards forward integration into higher value added fabricating activities. But they can also be tapped and transformed in the context of a strategic reorientation and transition towards ceramics production and use. Utilising and building upon existing strengths, economies, such as Zambia for example, can transfer metallurgical skills and technologies relatively easily into ceramics, such as dialectrics and ferrites, in the first instance. The production of dialectrics and ferrites has gradually been relinquished in Western Europe and the U.S.A., while Japan remains a major producer in parallel with its dominance in consumer electronics.

Brief outline of the transition path requirements:

1. Existing mining engineers and metallurgists would convert to ceramists. Qualified chemical engineers, materials scientists or chemists/physists could also apply themselves to ceramics.

2. Availability and training of local technologists and technicians/operators.

3. Enter into joint ventures, technology transfer and local training programmes with foreign firms, which could include firms in other developing countries as for example South Korea or Brazil.

4. Convert metallurgical furnaces and kilns for oxide/nitride ceramics.

5. Note that this transition is not difficult, and that metallurgy is easily transferred to ceramics.

6. Process involved:
   (a) Production of $BaTiO_3$

   Blend $BaCO_3$+$TiO_2$+additives

   Calcine at 1000-1100 degree°C → $BaTiO_3$ powder

   Add organic binders (cellulose etc.)

   Mill → fine powder

   Press ceramic shape → green body

   Stack in cheap oxide furniture (batts, trays etc.)

   Sinter at 1300-1400 degree°C → dense ceramic body, of final shape.

   Apply electrodes → silver based alloys as paints

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[10] I am indebted to Professor F. Ainger, Plessey Research, for detailed discussions and suggestions in this section

Brush and spray → fire at 50C degree°C → capacitor.

Similarly: (b) Ferrites: $ZnFe_2O_4$

(c) Substrates: $Al_2O_3$

(d) Piezoelectrics: $BaTiO_3$ or $PbZr_xTi_{1-x}O_3$

7. Markets for such materials and components are to be found in consumer electronics, radios, and television sets, as starting capacitors for fluorescent lights, etc.

8. Quality control involves chemical and X-ray analysis.

Clearly it makes sense for a number of developing countries in Africa, Asia and Latin America to seriously consider entering this field in order to supply domestic and regional needs for such materials in consumer electronics industries. The technologies involved are old and not hindered by patents, and the raw materials (e.g. technical barium) are cheap and accessible. Once entry has been achieved at this end of the market and these technologies are mastered, firms can then move on to more sophisticated products and technologies, since the technologies involved are similar.

## 4. Materials and the Environment.

Finally, it is important that improved and new advanced materials extraction, processing, application and recovery address the issues of environmental degradation and health hazards. These issues are no less significant and relevant in developing countries than they are in IAC's, and will come to exercise increasing influence over industrial strategy in NIC's in S.E. Asia and Latin America in the 90's.

While, on the one hand, materials production and use is inextricably being linked to environment concerns and hence, increasingly, to environmental and safety regulations, the materials revolution offers, on the other hand, scope for developing materials and technologies that can act so as to reduce or eliminate pressures on the environment.

In the production[11] of materials pollution can be generated by solvents during a curing cycle, or health risks may be present due to particle dispersion of ultra-short fibres in ceramics or composite fabrication, or the inhalation of fumes in reinforced plastics. In the use of materials, environment and health may again suffer and must therefore be controlled. A neglected but very important area refers to pollution generation by tarred surfaces (e.g. roads, car parks, airports, roofs etc.). Tar is essentially the rubbish damp of the petrochemicals industry, containing asphaltenes, heavy metals etc and can cause massive air and rainwater pollution, evaporation, water pollution etc. It is beginning to have deleterious effects also on pollution free soils in developing countries. Advanced materials solutions here could include the enclosure of tar and gravel in high-strength polymer pouch with controlled surface properties. This would give a large impetus to polymer producers, public works companies and the oil companies enabling them to eliminate residual tar and using the solid residues from the chemical industry's incinerator plants.

A major concern affecting all industries is the problem of recovery and recycling. New advanced materials pose greater threats and face even bigger difficulties in this area. New materials are increasingly complex (e.g.

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[11] P. Cohendet et.al., New Advanced Materials, Springer-Verlag, 1988.

composites or laminates) and more difficult to recover without destroying the materials. They are non-neutral to the environment, in the sense that they do not decompose and may be harmful in the long-run. Fibre-composites cannot be discarded after use and technologies do not exist to reuse the matrix fibre. And scrapped cars, washing-machines etc are increasingly less attractive for recovery and more difficult to separate.

The major areas of concern in the 90's include the development of high-technology recycling industries, without which new materials will find it increasingly difficult to diffuse. International cooperation would be needed to develop technologies and industries to deal with recovery processes for household and industrial wastes, with MSE in research labs and universities being directed to meet these needs.

Environmental concerns will be crucial to product development and materials selection in manufacturing industry and public utilities in the 1990's. New materials capabilities can assist in providing solutions to environmental concerns and regulations, and in the development of continuous-non destructive testing and sensor technologies that can enhance reliability and safety of components and final products.

Developing economies need to participate in the efforts to harmonise regulatory policy on environment, materials and health across IAC's, and the efforts to regulate production of hazardous of materials. In addition, collective efforts must be made to direct MSE towards resolving environmental problems and energy generation and distribution in developing regions through the production and use of new materials.

### 4.1.2 The crucial importance of enhanced competence in materials synthesis, processing and engineering.

Synthesis and processing as a unified series of activities by which new arrangements of atoms and molecules are transformed cost-effectively into materials and components refers to a wide range of activities, such as the rolling of aluminium and copper, the pressing and sintering of ceramic powders, thermomechanical processing of alloys, surface coating of metals, growth of gallium arsenide crystals, laying-up of composite materials, sol-gel production of pure ceramic powders and so on. Such techniques are essential for supplying industry with low-cost materials with requisite properties and performance characteristics. And, synthesis and processing capabilities are the essential mechanism by which new scientific and technological insights are transmitted into the production system in the form of useful materials and components.

The possession acquisition and continuous development of synthesis and processing pure and applied research capabilities and technologies is a critical determinant of competitive advantage for low-cost production in traditional materials industries and in the development and application of new materials. In fact, tremendous potential exists in the development of existing and long-standing processing technologies in traditional materials industries.

It is likely that a major component of commodity, industry and trade strategies in the 1990's would be the need for developing economies to strengthen engineering capabilities in the area of materials processing and fabrication technologies. The prudent and selective acquisition and strengthening of existing skills in processing and engineering technologies, coupled with the necessary educational, vocational training and infrastructural policies, would provide several developing economies with an effective mechanism with which to access new scientific developments, and a stepping stone towards the transformation of the industrial base while utilising the insights of MSE to meet domestic basic needs and a means for cost effective participation in the world market in traditional and, where appropriate, new materials. No economy can become involved in all materials, and specialisation therefore would be necessary. The acquisition of purely scientific capabilities per se is wasteful and possibly irrelevant for many developing economies.

### 4.1.3 Information, standards and quality assurance

The rapid proliferation of new and improved materials has highlighted the inadequacy of current definitions and standard classification schemes in terms of capturing the statistical importance of the phenomenon of advanced materials. At the same time it is becoming clear that access to up-to-date and comprehensive empirical information is vital to both industry and government in assessing the economic significance of advanced materials in terms of production, use, diffusion in specific sectors and displacement of traditional materials.

Access to information and data on materials properties and associated testing conditions, availability, producing companies, and quality assurance are emerging as a central determinant of global competitive advantage. It is important that LDC industry, universities, and other institutions not be excluded from such information. Hence, concerted effects must be made nationally, regionally and internationally to facilitate developing country on line access to materials data banks being developed currently in the IAC's, and participation in the efforts to harmonise the building of data bases across national economies, as is currently underway in the E.E.C. On the other hand, it is, and will become even more, important that a comprehensive inventory and data base of LDC's materials availability, properties, testing procedures and specifications, be built up over the next few years, since this is a primary consideration to industry in IAC's and other LDC's in terms of decisions to import and source materials and components or invest in plant utilising local materials.

A basic problem in building and accessing materials data base concerns standards and testing procedures employed across different industries, let alone countries. Very often there is a lack of compatibility in the properties and designation of engineering materials and the testing procedures under which they were obtained, as well as at the level of software, user interface, data presentation, terminology and data bank commands. The importance of upgrading or creating national and regional standards and testing institutes, the raising of awareness across industry of the need for quality assurance, and harmonisation of testing and specifications, and the coupling of this with the ongoing harmonisation of standards throughout IAC's must be a priority to LDC's, at all stages of development, in the new materials era of the 90's. This will play a significant role in international trade, foreign direct investment and transfer of technology in the years to come. Undoubtedly, standards and quality assurance will be the critical factor in new materials development, application and diffusion in industry in the 1990's and beyond.

### 4.1.4 Access to foreign technology and the role of MNC's

The aim must be to assist the development of domestic technological capacity and skills in a dynamic context. In this, training abroad, the acquisition of foreign technology and regional collaboration in research, training, standards and education would play a central role. Depending on the level of development of the productive forces some economies, such as Brazil, South Korea and Singapore may need and have opportunity to enter into joint ventures directly with companies engaged in advanced materials production in IAC's. Other countries may more usefully build upon their existing technological and traditional materials strengths by entering into collaborative agreements with firms and institutions in other developing countries in their region. Even though large corporations dominate in bulk materials another feature of the materials revolution is the importance of the small company accounting for the evidence of flexible specialisation and production for small market segments, too small for the larger companies. Countries need to closely examine the potential benefits of engaging in joint ventures and licensing agreement with either large MNC's or smaller specialised firms from IAC's in areas related to their existing resources and strengths. Such agreements could assist the efforts for forward integration and diversification of the export sector, enhance the skills, scientific capacity and managerial and technological know-how in a range of primary and manufacturing sectors, assist the penetration of foreign markets, enable the economy to accumulate experience in the use of new materials, and, where possible, facilitate the transition to advanced material production. For example, as part of a national scientific and industrial strategy, domestic traditional glassware and ceramic producers could be assisted to move to advanced ceramics production in the long run, with a prudent combination of enhanced domestic skills and acquisition of foreign technology. There are important lessons here from the evolution of the Japanese and South Korean ceramics industries in the 70's/80's. In the space of a few years South Korea has emerged as a major force in electronic ceramics, while its universities pour out ceramics graduate and doctoral students every year. (See section 4.3.1).

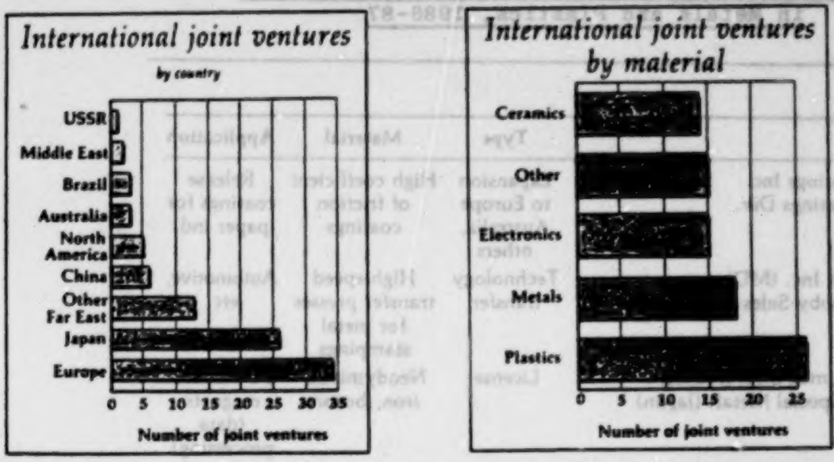
Internal corporate transformations into multimaterials competences are accompanied by strategies for vertical integration and diversification through mergers and acquisitions, to synergistically combine technological strengths in particular markets, licencing agreements and joint ventures. The materials market place is also characterised by growing internationalisation and fast transfer of technology across national boundaries.

In the US ceramics market the trend is towards vertical integration, due to inherent technological advantages, and for more acquisitions and mergers within the industry to consolidate the position in a currently small market. Most firms are seeking joint ventures, and this is also very popular in Japan constituting the main mechanism for penetrating this market. Acquisitions, joint ventures and licencing agreements are also becoming common in the European ceramics market.

US firms are using joint ventures in advanced composites as part of their efforts to penetrate foreign markets by assuming local identity. Interestingly, the US composites industry has used right from the beginning the licencing of basic technology from foreign firms, a point of obvious significance to developing economies. Licencing agreements constitute an important mechanism for the transfer of production and distribution rights for products into and out of a particular economy. On the other hand European firms have entered the US market through acquisitions and joint ventures.

Some evidence on early trends in materials related joint ventures, by country and by materials is shown in figure 6.1, below. Figure 6.2, presents example of joint ventures in metals and plastics.

Figure 6.1: International Joint Ventures in Materials



*Again, Japan is one of the leaders in international joint ventures, though China, in combination with other Far Eastern countries, is not too far behind. Countries like Brazil and Australia are emerging onto the scene.*

*Interest remains the highest in merging plastics technologies between countries, with metals a surprising second. For other Far Eastern countries like Korea, a similar trend exists, with electronics another strong contender.*

Source: Advanced Materials and Processes 8/87

### 4.1.5 Institutions and Government

The effectiveness of the organisational setting of government and institutions needs to be strengthened if economies are to come to grips with the complexities and practical implications of the materials revolution. An important requirement would be the creation of a central think-tank or council employing an interdisciplinary engineering and scientific team with the ability to monitor scientific and technological developments, analyse them and translate them into concrete industrial, educational and training domestic policies. Good examples here are the Secretariat on Advanced Materials in the Brazilian Ministry of Science and Technology, which comes directly under the Office of the President, and the Nucleus for the Study and Planning on Advanced Materials in the Brazilian Institute of Science and Technology, which is probably the first multi-disciplinary group to study advanced materials in a developing economy. Such a council should have the power to horizontally coordinate various government departments, monitor progress and implementation, and coordinate materials research in private industry, universities, research institutes and laboratories and government. All LDC's economies need to address the need for creating the appropriate institutions and mechanisms to effectively manage and respond to rapid change in the 1990s.

### 4.1.6 Human Resource Development.

In the age of advanced materials, highly qualified professionals will be as much in need as the acquisition of middle level skills and technicians for the unpackaging and use of new technology. Development economies must give the highest priority to the acquisition of skills at all levels through increased domestic education expenditures and training programmes, the training of nationals abroad, cooperative programmes across Africa, Asia and Latin America and participation in international scientific societies, consortia and trade associations. Greater emphasis must be given to pure scientific training and research and mechanisms must be sought for greater linkages between the conduct of R&D and its channelling towards commercial application in industry. The skills, competence and priorities of the banking

**Figure 6.2: Examples of International Joint Ventures in Metals and Plastics, 1986-87**

*Metals*

| Company | Type | Material | Application |
|---|---|---|---|
| Plasma Coatings Inc.<br>On Site Coatings Div. | Expansion to Europe Australia, others | High coefficient of friction coatings | Release coatings for paper ind. |
| M.S. Willett Inc. (MD)<br>Yamada Dobby Sales (Japan) | Technology transfer | High-speed transfer presses for metal stampings | Automotive, etc. |
| Aimants Ugimag S.A. (France)<br>Sumitomo Special Metals (Japan) | License | Neodymium, iron, boron | Permanent magnets (data processing) |
| Sheller-Globe (U.S.)<br>Ryobi Ltd. (Japan) | Joint venture co. | Aluminum, zinc | Die castings for front-wheel drive transmission |
| Rautomead Ltd. (Scotland)<br>China Metallurgical | Technology transfer of continuous casting | Copper, brass | Hollow extrusion billets for tubing |
| Rantaruukki Oy<br>Rasmet Ky (Finland) | License for heat treating coating steels simultaneously | High-strength deep-drawing steels | Galvanized products automotive |
| Indal Ltd. (Canada)<br>Indal Extrusion (GA) | New plant | Aluminum extrusions | Construction, auto |
| CMI International (MI) | New plant in Nuevo Laredo, Mexico | Cast aluminum parts | Auto engines |
| Schwarzkopf Dev. Corp.<br>Metallwerk Plansee (W. Germany) | New plant in MA (Machining) | Molybdenum, tungsten | Alloying steels, magnets, aerospace, electronics |
| Anoplate Corp. (NY)<br>Fothergill Engineering Surfaces (England) | License | Nickel coatings based on European process | Mold cores, pump rotors, valves, cylinders |
| Krupp Industrietechnik (W. Germany)<br>Pohang Iron & Steel (Korea) | New plant in Korea | Stainless steels | Automotive, construction, etc. |
| Inland Steel<br>Nippon Steel (Japan) | Joint venture I/N Tek | Cold-rolled sheet steel | Same as above |
| Elkem Engineering<br>Bank of Industry & Mines (Iran)<br>Sinai Manganese Co. (Egypt)<br>Stocksbridge Engineering Steels (England) | Technology transfer<br>Ferrosilicon plant | Iron, steel<br>Upgrade ferro-manganese, pig iron plant | Metals processing |
| | Elkem supplying automatic system for detecting, marking surface defects in steel billets | | |
| Alcoa (PA)<br>Umm Al-Qaiwain Aluminum Co. (Arabia) | Technology transfer (smelter) | Aluminum | Automotive |

contd.

**Figure 6.2, contd**

### *Metals*

| Company | Type | Material | Application |
|---|---|---|---|
| Kelsey-Hayes (MI)<br>Chuo Seiki Co. (Japan) | New plant | Aluminum, steel wheels | Automotive |
| Brush Wellman Inc. (OH)<br>Telcon Metals (England) | 25% buyout of Telcon | Beryllium copper alloys | Electronics |
| Bonal Technologies (MI)<br>United PentaCorp.(Prov.Taiwan)<br>Lauro Tool & Mold Consulting Co. (Hong Kong) | Marketing of Bonal's Meta-Lax process, which reduces stress of metals | | |
| Volvo Flygmotor AB (Sweden)<br>IHI Co. (Japan) | 3-year R&D program | Tungsten-reinforced superalloys | Aerospace |
| MPT (W. Germany)<br>MPT America Corp. (TX) | Market MPT/Thermin plasma nitriding equipment for ferrous- type materials | | |
| Babcock International (England)<br>Hunter Engineering Co. | Acquisition | Mill and process machinery for metals manufacturing | |
| Krupp Widia Corp. (W. Germany)<br>Ultra-Met Manufacturing (OH) | Acquisition | Tungsten carbide | Cutting tools |

### *Plastics*

| Company | Type | Material | Application |
|---|---|---|---|
| ARCO Chemical Co. (PA)<br>Yukong Ltd. (Korea) | Joint venture in Korea | Propylene oxide<br>Styrene monomer | Raw materials for eng. plastics |
| Mitsui Petrochemical Industries (Japan)<br>Enichem Sintesi (Italy) | Joint venture | Dimethyl carbonate<br>Transparent resin | Special chemicals |
| American Cyanamid Co.<br>Rohm GmbH (W. Germany) | Joint venture CYRO Industries | Acrylic sheet<br>Molding, extrusion compounds (methyl methacrylate) | Automotive<br>Construction |
| ARCO Chemical Co. (PA)<br>ATOCHEM (Belgium) | Acquisition of polyol plan | Flexible, rigid polyurethane foams | Insulation |
| Du Pont Co. | Build Belgium plant<br>Build Japanese plant | Polyimide bearings, seals, insulation<br>Perfluoroelastomer fluid seals | Auto, aerospace, electronic<br>Chemical, semi-conductors |
| Union Carbide<br>USI Far East Corp. | Build Taiwan plant | Linear low-density polyethylene resins | Films |
| Monsanto Chemical Co.<br>Mitsubishi Chemical | Build Brazilian, Japanese plants | Thermoplastic rubber and elastomers | Automotive<br>Aerospace |

**Source: Ibid.**

sector is an area of crucial interest here, in mobilising financial resources for materials ventures and training and educational programmes. A feature of the new era is that scientists, engineers and managers must be constantly updated and retrained.

## 4.2 Opportunities and needs for techno-economic and institutional cooperation.

### 4.2.1 Regional and international cooperation

Of recent, the implications of new materials for economic development have began[12] to receive attention in a number of regional and international meetings. A common theme that emerges is the strong need for regional and international cooperation and networking by developing countries institutions in the areas of materials information and data gathering, testing and standards, professional societies, experimental and laboratory facilities, and cooperation in research and development efforts across universities and industrial laboratories.

UNIDO has, appropriately and commendably, been especially active in this area. Apart from holding high level meetings on advanced materials, it is exploring possibilities for the establishment of regional centres of excellence and networking of standards and testing institutes across developing regions. In addition[13] it is in the definition stage of the establishment of a new international centre in Brazil, the purpose of which would be to provide centralised information and data services and engage in studies of a techno-economic nature addressing the transectoral complex and multi-disciplinary materials issues of relevance to developing economies in the 90's and beyond, in the framework of international cooperation. A complementary activity relates to the establishment of an International Centre for High Technology and New Materials in Trieste, Italy, which will engage in experimental and scientific work on semiconductors, superconductors and composites.

### A. The International Centre for High Technology and New Materials (ICTM)

The ICTM is being established in Trieste, Italy, as an international project implemented by UNIDO and with the cooperation of the Third World Academy of Sciences. It has the financial support of the Italian Government and is part of a broader institution, the International Centre for Science and High Technology (ICS). Through access to advanced instrumentation facilities and programmes of the ICTM, technologists and materials scientists from developing countries will be able to obtain practical and up to date experience and training in frontier developments in high-technologies and materials science. The promotional activities, aims and research programmes of ICMT are summarised below. 'Pilot activities' begin 1989-90 and the Centre is envisaged to reach a steady-state in the early 1990's.

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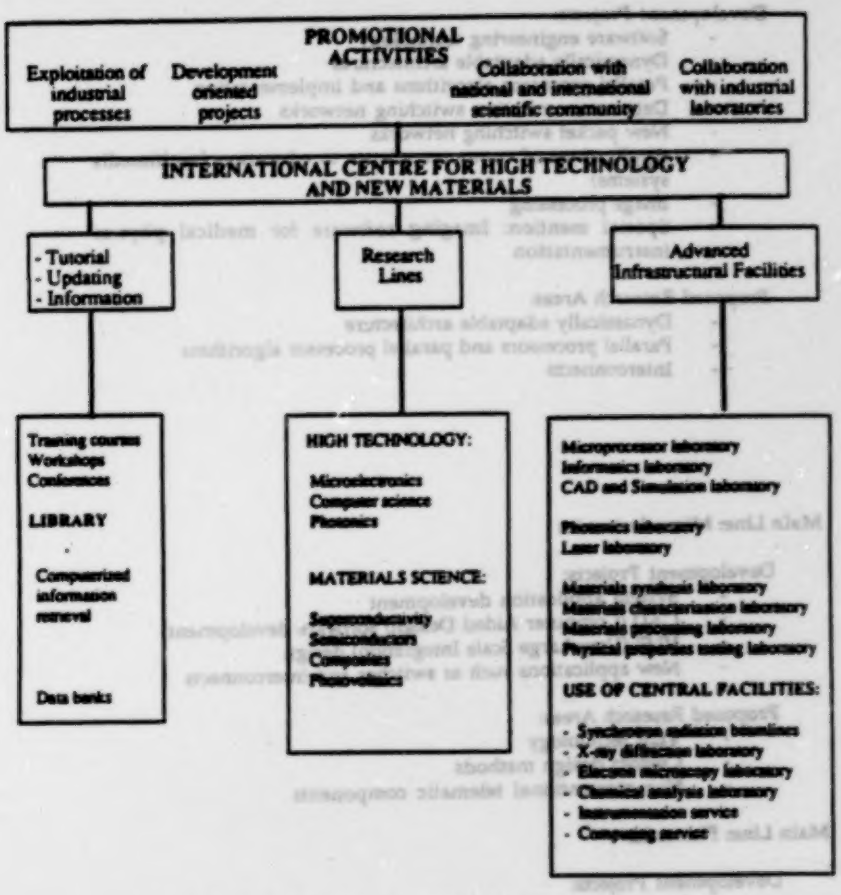
[12] See Report of the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk (USSR), 29th May - 2 June 1989. International Symposium on Advanced Materials in Developing Countries, World Materials Congress 24-30 September 1988, Chicago, USA. Final Report, Expert Group Meeting, UNIDO, Vienna, April 4-7, 1989, and Report, Discussion Meeting on Advanced Materials for Developing Countries, op.cit, UNIDO, Vienna, 7-10 December 1987.

[13] See L. Kaounides: "The establishment of an International Materials Assessment and Applications centre (IMAAC). A document by an expert mission on the design and definition phase of the project, 8th October - 17 November 1989". UNIDO, December 1989, pp 44.

Figure 7


PROMOTIONAL ACTIVITIES
Exploitation of industrial processes
Development oriented projects
Collaboration with national and international scientific community
Collaboration with industrial laboratories
INTERNATIONAL CENTRE FOR HIGH TECHNOLOGY AND NEW MATERIALS
- Tutorial
- Updating
- Information
Research Lines
Advanced Infrastructural Facilities
Training courses
Workshops
Conferences
LIBRARY
Computerized information retrieval
Data banks
HIGH TECHNOLOGY:
Microelectronics
Computer science
Photonics
MATERIALS SCIENCE:
Superconductivity
Semiconductors
Composites
Photovoltaics
Microprocessor laboratory
Informatics laboratory
CAD and Simulation laboratory
Photonics laboratory
Laser laboratory
Materials synthesis laboratory
Materials characterization laboratory
Materials processing laboratory
Physical properties testing laboratory
USE OF CENTRAL FACILITIES:
- Synchrotron radiation beamlines
- X-ray diffraction laboratory
- Electron microscopy laboratory
- Chemical analysis laboratory
- Instrumentation service
- Computing service

contd.

## Schematic Outline of Research Programmes

**High Technology**

**Main Line: Computer Science**

**Development Projects:**
- Software engineering technology
- Dynamically adaptable architectures
- Parallel processor algorithms and implementation
- Data communication switching networks
- New packet switching networks
- Applications of computer science to education (multimedia systems)
- Image processing
- Special mention: Imaging software for medical physics instrumentation

**Proposed Research Areas:**
- Dynamically adaptable architecture
- Parallel processors and parallel processor algorithms
- Interconnects

**Main Line: Microelectronics**

**Development Projects:**
- System application development
- CAD (Computer Aided Design) software development
- VLSI (Very Large Scale Integration) design
- New applications such as switches and interconnects

**Proposed Research Areas:**
- VLSI technology
- Custom design methods
- Non-conventional telematic components

**Main Line: Photonics**

**Development Projects:**
- Laser physics and technology (gas, dye, tunable lasers, etc.)
- Laser spectroscopy
- Application of lasers in medicine
- Optical fibres communication
- Optical image processing

**Research Areas:**
- Lasers for spectroscopy, remote sensing, medicine
- Advanced photonics materials
- Non-linear optics
- Optical sensors
- Integrated optics and opto-electronics

contd.

**contd.**

**New Materials**

**Main Line: Superconductivity**

**Proposed Research Areas:**

- Ceramic superconductors
- Metallic composites
- Superconducting films
- Superconducting devices
- Organic superconductors

**Main Line: Ultra-small Semiconductor Superstructures**

**Proposed Research Areas:**

- Development and study of new materials, new concepts and structures, new extreme physical situations (ultra-small sizes, ultra-short times, ultra-high fields, etc.).
- Identification and characterization of structure with potential devices of interest for microelectronics and opto-electronics (e.g. resonant tunnelling devices, infrared lasers, lasers of specific interest for the photonics activity).
- Spectroscopic studies of semiconductor superstructures, fabricated either in-house or elsewhere, aimed at identifying new tailor-made effects.

**Main Line: Composite Materials**

**Development Projects:**

- Polymer matrix composites (with glass, natural fibres from agricultural and mineral resources of developing countries).
- Metal matrix composites (with boron, carbon, graphite and silicon carbide, boron carbide, alumina fibres and particles, etc.).
- Ceramic matrix composites (for example, with silicon carbide whiskers, possibly made from rice husk, etc.).
- Protective coatings (for reinforcements and composites).

**Proposed Research Areas:**

- Design of composites with tailored properties.
- Selection of matrix, reinforcement, interface.
- Synthesis and characterization of reinforcing or filling fibres, particulates, whiskers.
- Computer simulation of properties, performance and synthesis of composites.
- Characterization and testing of composites.

**Main Line: Advanced Materials and Devices for Photovoltaic Conversion**

**Development Projects and Proposed Research Areas:**

- Preparation and characterization of:
  - α-Si:H and its alloys (with C, N, Ge, Sn), as well as of Schottky diodes; n-i-p simple, stacked or graded structures.
  - Direct gap semiconductors polycrystalline films, as well as Schottky diodes and heterojunction devices.
- Photoelectronic characterization of materials.
- Degradation (Staebler-Wronsky effect) and reliability problems.
- High-efficiency silicon cells.

## B. The increasing need for the establishment of an International Materials Assessment and Applications Centre (IMAAC)

The Discussion Meeting on Advanced Materials for Developing Countries, held in Vienna, 7-10 December 1987, recommended that "UNIDO promote the establishment of an International Materials Assessment and Applications Centre for an in-depth analysis and promotion of the rational use of materials".[14]

Following the December 1987 Discussion Meeting, the concept of and need for the Centre have been further discussed with several materials specialists in industry and government. The Government of Brazil expressed an interest in the establishment and hosting of the new centre, and, therefore, requested the assistance of UNIDO in this respect. UNIDO, in close consultation with the Government of Brazil, has therefore initiated steps for establishing a multi-disciplinary techno-economic International Materials Assessment and Application Centre (IMAAC) to be located in Brazil.

One of the most important objectives of the UNIDO programme on technological advances is, in fact, to promote necessary action to mobilise international and regional cooperation, particularly between the scientific and industrial community. This includes promoting the establishment of international centres and regional networks of centres of excellence in the field of new materials. The IMAAC project, while falling within these objectives, is an entirely new concept for which there is no parallel.

As part of this project two experts visited several sected institutions in Brazil, the United States of America, Japan and Europe, as part of the definition phase in the establishment of IMAAC. The results of the mission are encapsulated in the resulting Document,[15] which offers a broad outline and specific suggestions as to the design concept of the Centre, the functions to be performed and possible areas of international cooperation. The Document is currently under consideration by the Government of Brazil.

What this project seeks to establish and address is complementary to a number of other UNIDO activities and initiatives in this area. As discussed above, an International Centre for High Technology and New Materials dealing with semiconductors, superconductors and composites is being promoted as part of an International Centre for Science and High Technology in Trieste, Italy. This is an experimental and scientific centre, whose output and expertise can form a useful complement to the analytical and networking activities of IMAAC.

Further, Expert Group Meeting on Prospects for Industrialisation Policies in Developing Countries Taking into Account the Impact of Developments in the field of New and High Technologies, Vienna, 4-7 April 1989, further reiterated the need for the establishment of a new international centre to assist developing economies in the rapidly changing scientific and technological circumstances in the materials field (Report, PPD.116(SPEC.), 24 May 1989). The meeting was requested by the Group of 77, and the conclusions and recommendations made in the summary report were subsequently adopted by the Group 77 in Vienna. The report was also adopted by the Intergovernmental Committee for follow-up of the ECDC/TCDC which was held in Kuala Lumpur in 1989, which then recommended that the ministerial meeting of the G77 in New York also adopt it.

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[14] Report, UNIDO, IPCT, 53(SPEC.) 24 February 1988.

[15] See Kaounides, 1989, op.cit. note (12).

## Materials issues; complex, multidisciplinary and transectoral

Materials issues are today multidisciplinary in nature and transmaterial and transectoral in impact. They must therefore be addressed as such. Examining the issues through the lens of a specialised materials institution, such as iron and steel or primary aluminium institutes, or individual commodity specialists is grossly inadequate in the current circumstances. Today's research output is monomaterial orientated and highly specialised. There is thus no central institution in which a multidisciplinary approach is adopted to study problems which span several materials. The central problems at hand are highly difficult, complex and elusive going across disciplines, specialised institutions and traditional approaches. The new circumstances and the new problematique thus call for a new approach. The concept and structure of IMAAC is thus both timely and necessary in order to meet the pressing need for a multidisciplinary, transectoral approach to materials issues facing developing economies. The centre would be able to grapple with the diffuse nature of the problems, cut across the complexities, and pull together the essentials of the issues facing specific industries and economies.

## Materials management in transition

At the national level there is considerable lack of awareness and institutional capacity to monitor global trends and translate them to domestic industrial policy. At the same time materials strategies and materials management and planning are in a transition, calling forth much greater analytical and informational content than the traditional monomaterial preoccupations and central concerns with export prospects. While the economics side concentrates on export prospects and price and income elasticities, another area receiving attention in materials relates to the science base, laboratories, testing procedures and so on, with the two areas completely separated. Yet the latter is clearly an organic part of materials strategy and can be a central ingredient in a materials strategy. IMAAC can help to fill this analytical gap and assist developing economies to build institutions and skills to address materials issues in a comprehensive manner and develop appropriate materials strategies in the 90's. An important element of this must be the recognition of the differing needs of economies at different stages of their development and with materials displaying various degrees of importance in the national economy and exports.

## Environmental issues

Another major area of increasing international concern, relates to environmental issues. Rather than the fragmentary and incomplete approach now underway regarding the environmental problems involved at all stages of materials extraction, processing, manufacture, recycling and disposal, especially in plastics, IMAAC can provide a centralised framework whereby awareness is raised on these issues in developing economies and such that they are approached in a concerted, informed manner in the framework of international cooperation.

## Networking

It is not sufficient to network existing institutions in order to deal with the issues identified above. IMAAC can perform an indispensable function by identifying and utilising the strengths of existing institutions in developing countries and by providing a central umbrella and intermediation mechanism whereby university departments, scientific research centres and laboratories, professional societies, technical experts and information and data bases can be networked and put into contact with each other to enhance efficiency and international cooperation as well as the ability to centrally utilise these strengths in order to address materials problems faced by national economies and industries.

## The pressing need for a new multidisciplinary, international centre

The remarks above highlight the enormous tasks, analytical needs and informational requirements imposed by the revolution now embracing the whole materials field across both producers and users in industry. Such tasks are beyond the means of a single specialised research institute, professional society, firm, or ministry. There is now a pressing need for the establishment of a new international multidisciplinary centre which can centrally address:

a. the in-depth investigation of trends in materials science and engineering and in the field of advanced materials, and relate these to the role of traditional and new materials in a restructuring world industry moving towards high-value added knowledge intensive production;

b. the assessment of the resources available in specific developing economies, their future prospects in meeting domestic needs and/or global industrial market needs, and the role of the materials sector in a future industrialisation programme;

c. the need to build up institutions, and attendant materials education and training programmes in developing economies;

d. the gathering, assessment, and dissemination of vast historical and continuously up-dated information and data on new improved traditional and advanced materials of relevance to developing economies;

e. the need to intermediate across institutions, professional societies and expertise in materials related fields in developing economies to raise awareness of materials issues for national economies and to network existing national and regional data and standards institutes under a single umbrella.

This serious ongoing effort, therefore, to establish IMAAC is a very timely and much needed international venture designed to meet a perceived analytical and information gap to provide developing economies with a centralised institutional framework not available which can assist them to address materials issues of continuing importance to their economies in the years to come.

### 4.2.2 South-South trade in an open and dynamic world economy.

In addition, there is clearly an important role here for South-South trade as production capacity and infrastructural requirements expand in countries at different levels of development. It is interesting to note the changing direction of developing country primary commodity exports in recent years, as Table 6, shows:

**Table 6: Changing destination of exports of primary commodities from developing countries**

(Percentage share of intra-developing country exports in total developing country exports)

| | 1973 | 1980 | 1986 |
|---|---|---|---|
| Food | 17.9 | 23.5 | 19.9 |
| Raw materials | 22.7 | 26.1 | 27.7 |
| Ores and minerals | 6.7 | 11.5 | 18.2 |
| Non-ferrous metals | 11.0 | 15.7 | 22.7 |
| Fuel | 18.6 | 22.2 | 27.9 |
| Total primary products | 18.0 | 22.1 | 24.9 |
| Excluding food and fuel | 16.0 | 19.3 | 23.6 |

Source: World Economic Survey, 1989, UN, ST/ESQ/211.

As industry has been growing in the more industrialised LDCs, this has provided expanding markets for primary exports from other LDCs. Most of the increase has been due to imports by Asian LDCs. In fact, exports of primary non-fuel commodities from Asian economies to other Asian economies as a percentage of their total exports went up from 22.5 per cent during 1966-70 to 34 per cent during 1983-85, while exports from African and Latin American LDCs to other LDCs also registered large increases in the same period. There may well be further scope for South-South primary trade, especially if trade barriers come down. But it must be remembered that the industrialisation process, especially in the first tier NICs, will also be accompanied by the application of sophisticated manufacturing technologies, and this will have repercussions on the type and quality of materials, including advanced materials, required.

The 42 least developed economies (UNCTAD, Trade and Development Report 1989), comprise of a population of 340 million, and are distinguished from other developing economies, because of even lower levels of per capita income, lower levels of adult literacy, smaller share of manufacturing in total GDP, lower savings and investment rates, very large percentage of labour in primary, mainly subsistence sector, and high export concentration on few, mainly primary, commodities (65% of total export earnings in 1986). At the same time they suffer from a very weak infrastructure with poor networks of communication and transport.

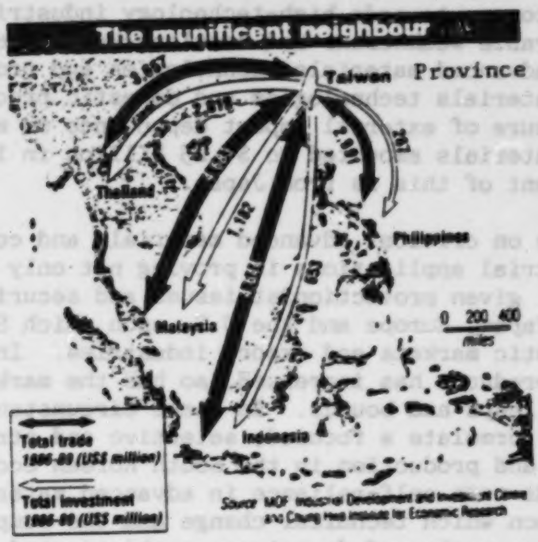
During the 1980's they experienced enormous cutbacks in education and teacher training programmes, while investment to maintain a deteriorating industrial and infrastructural base has been lacking. These economies have effectively been marginalised in the world economy, with their combined world export market share in 1987 being a quarter of its value two decades earlier, while the share of other developing countries remained constant during this period. Their export markets are heavily concentrated, mainly to the EEC, while their markets in other developing countries are generally low. Clearly, the changing materials and manufacturing conditions in the world economy pose a real threat to further marginalisation of these economies in the 1990's, unless action is taken now to upgrade their educational, training, engineering, standards and quality control, and institutional capabilities consistent with existing resources and strength. South-south trade and regional collaboration in R&D, training, information and data, and standards institutes networking would play an important role in the effort to target and selectively acquire dynamic comparative advantage opportunities. It must be noted that several of these economies, especially in sub-Saharan Africa are actually rich in resources.

If we now look at the NIC's, and the four in south-east Asia in particular, we see that their industrial structures are moving towards high-value added, sophisticated products and are finding themselves in need to enter into joint ventures or conclude licensing agreements with foreign companies in order to upgrade their technological capabilities. While wages have been rising in these economies, domestic firms have been looking to neighbouring economies for cheap labour and foreign firms, especially Japanese, are either relocating labour intensive activities from Taiwan Province and South Korea to other economies or have been avoiding these relatively high wage economies altogether in recent years. On the other hand, higher wages, a developed infrastructure and higher workforce skills, have altered the attractiveness of the four economies to foreign firms. Foreign direct investment now flows in highly skilled, sophisticated activities, while higher wages imply larger markets encouraging the inflow of foreign firms. Moreover, foreign firms now locate there to produce sophisticated components and advanced materials for domestic use or re-export to Japanese industries.

Therefore, there is a dynamic process under way in east Asia whereby the move to higher-value added industrial activities by the rapidly industrialising NIC's, has created vacancies or opportunities to other countries in the region to enter into relatively more labour intensive industries and segments of the production process. Lower wage economies such as Thailand, Malaysia, the Philippines and Indonesia can thereby expand their industrial base and expertise by building on existing strengths and competitive advantages, without neglecting the need to build their educational, scientific and technology skills. These second tier economies also possess considerable natural resources entering world trade, in comparison to the four first tier NIC's mentioned above. On the other hand they have serious infrastructural constraints, as in the unreliability of the electricity system.

Evidence of the remarkable surge of foreign direct investment by Taiwan Province firms to neighbouring economies offering good infrastructure and cheaper labour is shown below. In 1989 Taiwan Province was responsible for US $776.5 million worth of foreign manufacturing investment, second only to Japan, to Malaysia. There are about 200 Taiwanse Province factories in Malaysia, mainly in electronics, but also in petrochemicals, banking and furniture manufacturing. In Indonesia, Taiwan Province again ranks second to Japan in realised investment, nearly all of it taking place in the last two years. Investment projects have mainly utilised Indonesian low-wages labour in labour-intensive footwear and textile plants, and in wood processing and furniture factories.

**Diagram 5: Taiwan Province: Regional trade and investment 1986-89**


The munificent neighbour
Taiwan Province
3,857
2,818
2,001
707
1,187
Thailand
Philippines
Malaysia
Indonesia
0 200 400
miles
Total trade
1986-89 (US$ million)
Total investment
1986-89 (US$ million)
Source: MOF, Industrial Development and Investment Centre and Chung-Hua Institute for Economic Research

Source: Far Eastern Economic Review, 19 April 1990.

## 4.3 Advanced materials in developing countries

**The potential for entry and the experience of developing countries in advanced materials varies greatly between countries at different stages of socio-economic and industrial development. A number of international gatherings and publications[16] have began to address the multitude of needs and opportunities across the spectrum of developing economies. Nevertheless, such efforts together with assistance provided by international organisations and regional centres of excellence can only provide broad guidelines, common points of reference and set the parameters within which each economy can devise its own materials, technology and industrial strategies in consonance with domestic needs and resources. In this section we offer but a brief overview of advanced materials production and use in two rapidly industrialising developing economies, the Republic of Korea in South East Asia and Brazil in Latin America.**

### 4.3.1 SOUTH KOREA

**The South Korean economy[17] has shifted from labour-intensive manufacturing activities characterising the period of the 60's, to technology-intensive, heavy industries in the 70's, such as cars, shipbuilding, steel, chemicals, and then towards more sophisticated, high-tech, higher value-added, knowledge intensive activities in the electronics, computer, information and telecommunications industries in the 1980's. In the 1970's, basic industries in chemicals, steel and non-ferrous metal expanded substantially, so that the domestic requirements of**

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[16] See, for example, ATAS Bulletin 'Materials technology and development', Centre for Science and Technology for Development, U.N., New York, 1988. Report of the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk (USSR), 29 May 2 June, 1989. And, Materials Developments in Selected Countries, Advances in Materials Technology: Monitor, UNIDO, Issue No. 16, January 1990.

[17] See Dr. Chungi Rhee, 'Status and Prospects of New Materials Technology in Korea', Regional Workshop on Advanced Materials Technology Development, Minsk (USSR), 29 May - 2 June 1989, and, Sung Do Jang, 'Recent Developments in the Advanced Ceramics Industry of Korea', Ceramic Bulletin, Vol 67, No 9, 1988.

conventional materials is reasonably well provided for. On the other hand, the structural adjustment of the economy towards high-technology industries has, in recent years, unmasked considerable weaknesses and bottlenecks of the economy in the area of adequate domestic advanced materials technologies and production. The relative neglect of advanced materials technologies and domestic processing capacity has meant a large measure of external import dependence on materials and components, so that imported materials amounted to $4.25 billion in 1986 and $5.7 billion in 1987. Eighty per cent of this is from Japan.

This external import dependence on critical advanced materials and components entering high-technology industrial applications is proving not only costly but is also fraught with difficulties, given protectionist issues and security considerations on the part of Japan, Europe and the U.S. upon which S. Korea relies to meet the needs of both domestic markets and export industries. Indeed as the domestic market for high-tech products has increased, so has the market for new and advanced materials expanded by leaps and bounds. In these circumstances, there emerged a self-evident need to formulate a focused, selective and strategic approach to materials research and production in the South Korean economy. The need to upgrade and move towards more self-reliance in advanced materials research and production technologies, upon which technical change and the competitiveness and export performance of a large number of downstream sophisticated industries largely depends, has emerged as paramount. The domestic development and processing of advanced materials and components thus becomes a matter of vital importance to sustained patterns of industrialisation and the orientation of the industrial structure towards high-technology. Nevertheless, a central feature of the materials revolution, which is clearly reiterated in the S. Korean context, is the fact that the development and application of new materials is impossible without access to highly sophisticated advanced precision instruments and measurement technologies, as well as commonly accepted standard references and procedures. Hence the development of characterisation, analysis and evaluation technologies and associated standardisation of methods of evaluation are emerging as critical and indispensable components of a national materials and high technology strategy not only in IAC's, but also in rapidly industrialising economies such as S. Korea. The S. Korean example is therefore richly instructive as to the indissoluble links that are emerging between high-technology industries and the supply of advanced materials and components, and, the parallel, critical importance of national measurement technologies and standard evaluation methods. In this respect the activities of the Korean Standards Research Institute are given in Diagram 6.

Electronic Ceramics

S. Korea is emerging as a major force in world electronic ceramics and a serious challenge to Japanese pre-eminence. The development of the electronic ceramics industry of S. Korea is closely intertwined with the evolution of the electronics sector, which currently constitutes around 10% of manufacturing production and over a fifth of manufacturing exports. In fact electronics in the 1980's, has been performing as a dynamic leading sector with all the attendant backward and forward linkage effects to the rest of the economy.

## Diagram 6: The Korean Standards Research Institute

**KSRI**: Established in 1975 as a central authority of the national standards system.

Has established national measurement standards in 80 measurement fields.

The development and application of new materials relies on a set of basic technologies:

| | |
|---|---|
| Technologies for Beam Generation: | Microlithography, annealing, milling, elimination of defects in ceramics, surface quality improvements of organic conducting materials.<br>Electromagnetic waves: $\gamma$-rays, X-rays, ultraviolet rays.<br>Particle Beams: electrons, positrons, neutrons protons, atoms, ions. |
| Extreme Environment Generation: | These technologies are indispensable for studying new phenomena, creating new materials, precision measurements and extreme environments, and analysis/evaluation of new materials. |
| Analysis and Evaluation: | Essential for the creation, application and quality assurance of new materials. |

The KSRI conducts, therefore, research on: Precision measurement technology, advanced precision instruments, extreme environment generation technologies, ultra-low, ultra-high temperature, ultrahigh pressure, ultra-high vacuum and ultra-clean room environments, and beam generation technology for new materials analysis.

In analysis/evaluation technologies research is conducted on:

- Evaluation of materials strength at 4.2K
- Characterisation of piezoelectric materials
- Characterisation of Si-steel
- Analysis of inorganic materials at ppb level with GD-MS.

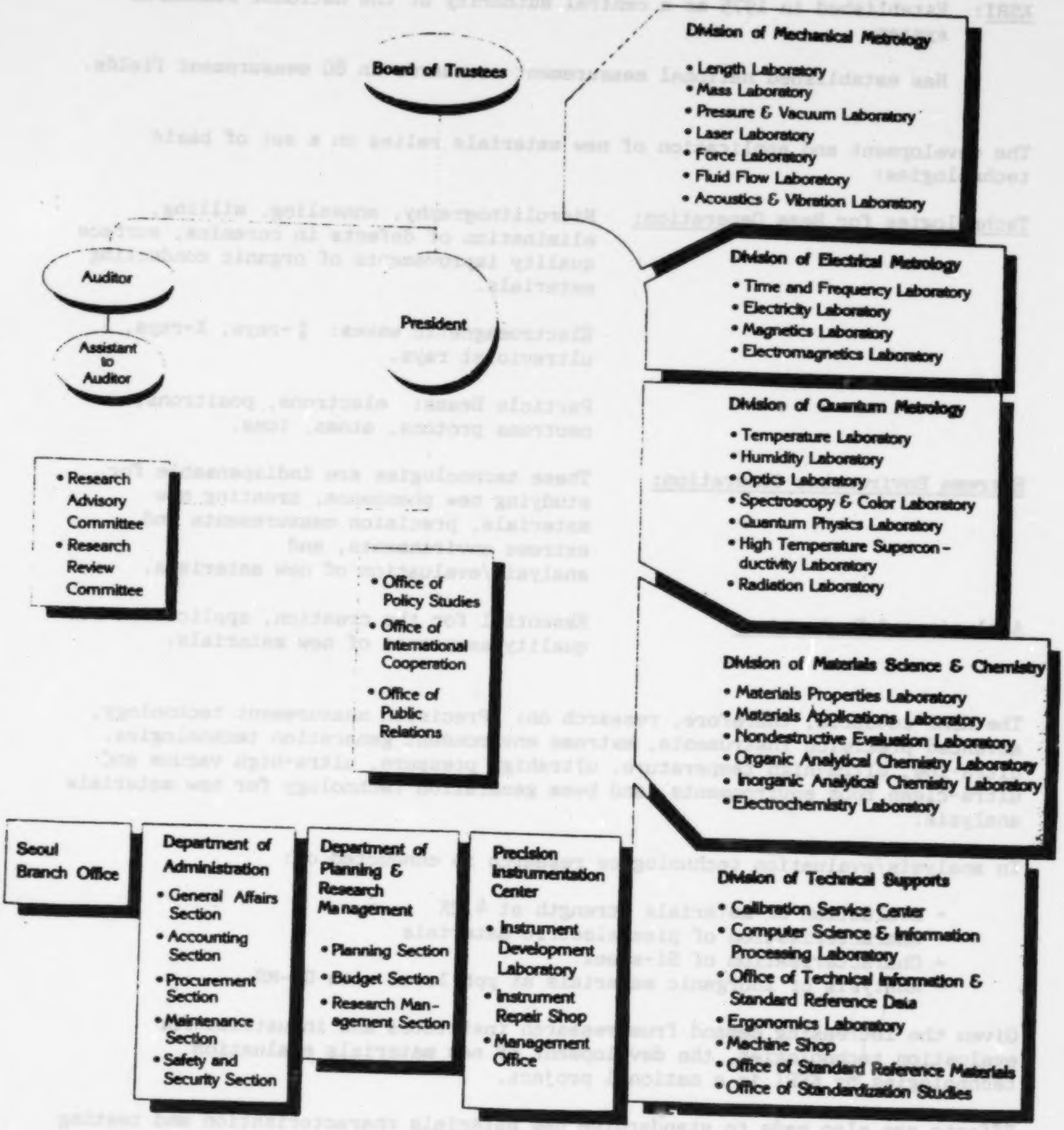
Given the increasing demand from research institutes and industries for evaluation technologies, the development of new materials evaluation technologies by KSRI is a national project.

Efforts are also made to standardise new materials characterisation and testing procedures across countries: Recognition that standards require international coordination and cooperation to facilitate industrial application and trade.

Source: Adopted from C. Rhee, 1989, op.cit.

Diagram 6 (contd)

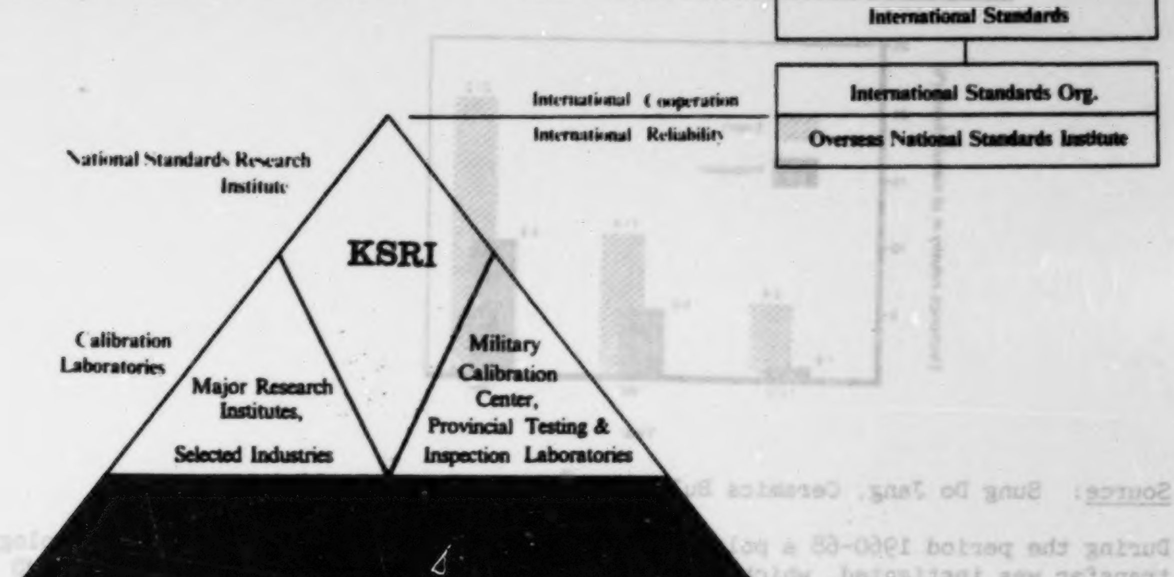
## Organization


Board of Trustees
Auditor
Assistant to Auditor
President
• Research Advisory Committee
• Research Review Committee
• Office of Policy Studies
• Office of International Cooperation
• Office of Public Relations
Division of Mechanical Metrology
• Length Laboratory
• Mass Laboratory
• Pressure & Vacuum Laboratory
• Laser Laboratory
• Force Laboratory
• Fluid Flow Laboratory
• Acoustics & Vibration Laboratory
Division of Electrical Metrology
• Time and Frequency Laboratory
• Electricity Laboratory
• Magnetics Laboratory
• Electromagnetics Laboratory
Division of Quantum Metrology
• Temperature Laboratory
• Humidity Laboratory
• Optics Laboratory
• Spectroscopy & Color Laboratory
• Quantum Physics Laboratory
• High Temperature Superconductivity Laboratory
• Radiation Laboratory
Division of Materials Science & Chemistry
• Materials Properties Laboratory
• Materials Applications Laboratory
• Nondestructive Evaluation Laboratory
• Organic Analytical Chemistry Laboratory
• Inorganic Analytical Chemistry Laboratory
• Electrochemistry Laboratory
Seoul Branch Office
Department of Administration
• General Affairs Section
• Accounting Section
• Procurement Section
• Maintenance Section
• Safety and Security Section
Department of Planning & Research Management
• Planning Section
• Budget Section
• Research Management Section
Precision Instrumentation Center
• Instrument Development Laboratory
• Instrument Repair Shop
• Management Office
Division of Technical Supports
• Calibration Service Center
• Computer Science & Information Processing Laboratory
• Office of Technical Information & Standard Reference Data
• Ergonomics Laboratory
• Machine Shop
• Office of Standard Reference Materials
• Office of Standardization Studies

Source: Korea Standards Research Institute

Diagram 6 (contd)

## National Calibration System


International Standards
International Standards Org.
Overseas National Standards Institute
International Cooperation
International Reliability
National Standards Research Institute
KSRI
Calibration Laboratories
Major Research Institutes,
Selected Industries
Military Calibration Center,
Provincial Testing & Inspection Laboratories

Research Institutes, Testing and Inspection Laboratories

Educational Institutes, Industries

## Training

Various training courses are provided in order to enhance the industrial capabilities in precision measurements : the managerial course for top managers and those who are in charge of quality controls specialist. the course for those specialized in certain fields of precision measurements. and the technician course for those who do not have much experiences in precision measurements.

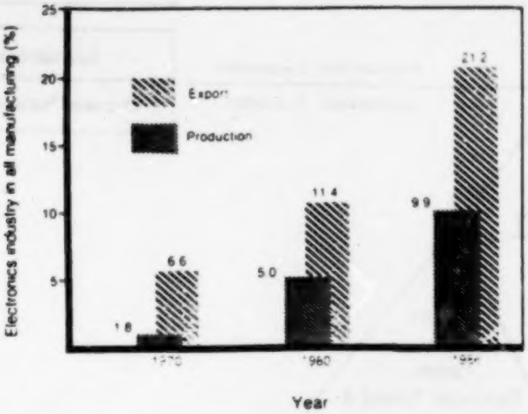
**Tranining Fields**

| Fields | Contents |
|---|---|
| Mechanics | Length, Mass, Force, Fluid Flow |
| Electricity | Direct Current, Alternative Current, Magnetism |
| Time | Time & Frequency, Electromagnetic Waves |
| Temperature | Low Temperature, High Temperature, Medium Temperature |
| Optics & Acoustics | Optics, Acoustics, Vibration |
| Chemistry | Gas Analysis, Atomic & Molecular Analysis |
| Materials | Property of Materials, Nondestructive Testing |

**Training Courses**

| Courses | Fields | Trainee |
|---|---|---|
| Managerial Course | National Standard System, Quality & precision measurement | Top managers & Directors of Q.C. |
| Specialist Course | Theory and practice of precision measurements in the specific fields concerned. | Specialists in the offered fields |
| Technicians Course | - | Technicians |

Figure 8: The Korean Electronics industry as a proportion of all manufacturing output and exports 1970, 1980, 1986



Source: Sung Do Jang, Ceramics Bulletin, vol. 67, No 9, 1988.

During the period 1960-68 a policy of encouraging foreign investment and technology transfer was instigated, which resulted in the domestic production of radios, EMD telephone switching machines, televisions and semi-conductor assembly via foreign direct investment. Between 1969-75, the enactment of the Electronics Industry Promotion Law sought to improve testing and quality control, enter export markets, upgrade domestic industry, and thereby assisted in domestic assembly of colour TV's and cassette records, as well as the mass production of circuit elements, such as resistors, condensers, and switches. Subsequently, the period 1976-80 saw an enhanced transfer of technology and efforts of unpackaging and duplicating it, while R&D organisations began to be formed. The 1980's witnessed a period in which sustained efforts were made to develop domestic electronics related technologies. Exports of products such as colour TV's and microwave ovens grew, while domestic assembly and production of computers, VLSI's, electronic materials, VCR's and telecommunications equipment also expanded meeting local market demand for most products apart from very sophisticated ones.

Despite, or because of, the rapid expansion of exports of consumer electronics in the 1980's, certain structural weaknesses came sharply to the forefront. The remarkable rise of electronics production and exports was accompanied by a rapid rise in electronic parts, components and materials. Apart from the considerable balance of payments, strains that this imposed, S. Korean manufacturers experienced severe difficulties in terms of timely delivery of imported parts, and high costs due to price manipulation. In 1985, for example, S. Korean exports of electronic products to Japan stood at $430 million, and imports were valued at $1.360 million, as a direct result of the very high dependence on Japan for imported electronic parts and materials.

Given the vast domestic market for electronic ceramic parts and materials, together with the impediments to domestic production, growth technical change and export performance of excessive foreign reliance, efforts have been underway, stretching back to the 1970's, to promote an indigenous electronic ceramics technological and productive self-sufficiency. But moving in this direction has also encountered constraints, where the chosen method was the licencing of foreign technology. The licencing of appropriate technology is difficult, involves high royalty costs and inbuilt contractual limitations. Hence, in recent years, the importance of acquiring domestic, in-house R&D capabilities in advanced ceramic materials and components has been recognised by S. Korean firms, and this has been supported by the Government in a special national project in which industry is supported both financially and technologically in this area.

The development[18] of the electronics industry has therefore nurtured the gradual development of a domestic electronic ceramics industry upon which it depends for future growth and export competitiveness. In turn, though, the electronics ceramics industry is dependent on raw material imports. Thus, while insulating ceramics, such as ceramic rods for carbon film resistors and insulators for surge arrestors are currently produced domestically, raw materials, which include alumina powders, are entirely imported. And, while the largest domestic market is for alumina substrata and packages, there was until recently no domestic production. Although electronic ceramics are manufactured by traditional ceramic processes, nearly all the raw materials, except ferric oxide, are imported. The further development of electronic ceramics and the steps taken towards greater self-reliance, require vast improvements in the domestic ceramic raw materials industry, and progress has been achieved in this direction.

The greatest demand for advanced ceramics, at present, naturally is generated by the electronics industry. Table 7 shows the demand and production of advanced ceramics in Korea for 1984 and 1987. Structural applications for advanced ceramics are currently limited for the size of the domestic market. Nevertheless, given the large entry of firms and non-electronic industries into ceramics recently, Korea will also become a force in structural applications in world markets.

Table 7: Demand and Production of Advanced Ceramics in Korea ($m.)

| Items | 1984 | | 1987 | |
|---|---|---|---|---|
| | Demand | Production | Demand | Production |
| Structural, wear-resistant ball-mill liners, thread guides, tool-bit, etc. | 5.5 | 1.2 | 15.8 | 4.4 |
| Insulators<br>IC package, substrates, metallized ceramics, etc. | 62.5 | 1.2 | 103.3 | 4.0 |
| Capacitors<br>disk, MLCC, B-L, F-T, etc. | 32.3 | 25.5 | 83.2 | 41.6 |
| Piezoelectrics<br>filters, quartz, buzzer, ignitors, etc. | 23.7 | | 46.0 | 8.0 |
| Ferrites<br>soft, hard, magnetic heads, recording media, calcines, etc. | 78.5 | 38.0 | 227.7 | 94.2 |
| Semiconducting<br>thermistors, sensors, varistors, etc. | 10.8 | | 34.0 | 2.8 |
| Carbon and others | 32.6 | | | |
| Total | 245.9 | 65.9 | 510 | 155.0 |
| Production versus demand (%) | | 26.8 | | 30.4 |

Source: Sung Do Jang, 1988

Table 8, shows details of current activity in Korea's Advanced Ceramics Industry, and Table 9 and 10, together with Diagram 7, show manufacturers of ferrites, capacitors and wear-resistant and insulating ceramics. Of the 67 companies involved in ceramics, 20 mass produce magnetic materials (soft and hard ferrites and magnetic materials), 18 are involved in piezoceramics, two produce semiconductors and seven are developing technologies for the latter. Most are small scale firms, except those producing ferrites and capacitors. Piezoceramics comprise less than 10% of demand, semiconducting ceramics are less than 7% and structural, non-electronic ceramics even less.

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[18] See L.M. Sheppard, 'Korea: A Major Force in Electronic Ceramics', Ceramic Bulletin, Vol 67, No 9, 1988.
Soon-Ja Park, 'Electronics: Dependent on Raw-Material Imports', Ceramics Bulletin, Vol 67, No 9, 1988.
Sun Do Jang, 'Recent Developments in the Advanced Ceramics Industry of Korea', Ceramic Bulletin, Vol 567, No 9, 1988.

## Table 8: Current Activity in Korea's Advanced Ceramics Industry

| Item | Number of firms | Demand ($million) | Activity: 1987 production | Activity: Development stage[a] |
|---|---|---|---|---|
| Structural and wear-resistant ceramics | | | | |
| Tool bits | (2)* | 1.5 | Negligible | 1988 |
| Structural components[b] for automotive applications | | 4.0 | | |
| Wear-resistant (thread guides, tiles, balls, sandblast nozzles, mechanical seals | 3 | 10.3 | 4.4 | |
| Total | 3 (2)* | 15.8 | 4.4 | |
| Insulating ceramics | | | | |
| IC packages | (2)* | 87.6 | | 1989 |
| Substrates | 1 | 6.2 | 0.8 | |
| Resistors | 1 | 2.5 | 2.2 | |
| Metalized ceramics (for surge arrestors, magnetrons, SCR housing) | 1 (2)* | 7.0 | 1.0 | 1988 |
| Total | 3 (4)* | 103.3 | 4.0 | |
| Capacitors | | | | |
| Disk type | | 45.0 | 35.3 | |
| MLCC | | 23.5 | 6.3 | 1987 |
| BL, F-T, etc | | 14.7 | | 1988 |
| Total | 8 | 82.3 | 41.6 | |
| Piezoelectric ceramics | | | | |
| Ignitors | (3)* | 2.0 | Negligible | 1988 |
| Buzzers, ringers | 3 | 5.4 | 2.0 | |
| Filters (PZT, SAW, quartz) | 8 | 25.0 | 6.0 | 1989 |
| Oscillators, others | 4 | 15.6 | | 1989 |
| Total | 15 (3)* | 46.0 | 8.0 | |
| Magnetic ceramics | | | | |
| Ferrite powders (Ba-, soft ferrite) | 2 (2)* | 15.8 | 12.2 | 1988[c] |
| Magnets | 5 | 42.3 | 33.8 | |
| Soft ferrite cores (DY, FBT, EE, EI, etc.) | 5 (1)* | 54.9 | 48.3 | |
| Magnetic recording heads (audio, VCR, HDD, FDD) | 7 (1)* | 116.8 | | HDD, 1988;<br>VCR, 1989 |
| Recording media ($\gamma$-$Fe_2O_3$, Co-$Fe_2O_3$) | 1 (1)* | 52.8 | Negligible | 1987 |
| Total | 20 (5)* | 227.7 | 94.3 | |
| Semiconducting ceramics | | | | |
| Thermistors (PTC, NTC) | 2 (2)* | 19.2 | 0.8 | 1988 |
| Sensors (oxygen, gas, thermo, humidity, etc.) | (3)* | 8.3 | | 1988 |
| Varistors, arrestors | (2)* | 6.5 | 2.0 | 1987 |
| Total | 2 (7)* | 34.0 | 2.8 | |

*Numbers in parentheses indicate new entrants. [a]Year for production. [b]Includes thermal applications. [c]$\alpha$-$Fe_2O_3$.

Source: Ceramic Bulletin, 1988

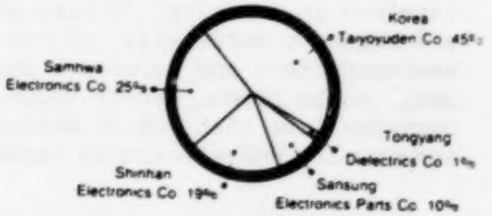
## Table 9: Manufacturers of Wear-Resistant and Insulating Ceramics

| Company | Products |
|---|---|
| Sunkwang Ceramics Co. | Surge arrestors, cement resistor case |
| Cheil Ceramics Co. | IR plate, gas burner tip (ball ceramic liner) |
| Taepyung Electronic Ceramics Co. | Thread guide, ball ceramic liner |
| Yudong Co. Ltd. | Alumina rod for carbon film resistor |
| Namsung Ceramics Co. | Cement resistor case (welding backup) |
| Changwon Co. Ltd. | Insulator (ceramic liner) |
| Samhaeng Electric Co. | Ignition plug for gas cookers |
| Samsung Ceramics Co. | Ceramic insulator |

## Table 10: Ferrite Manufacturers in Korea

| Company | Products |
|---|---|
| Soft | |
| Samhwa Electronics Co. | DY, FBT, EI, EE cores; rotary transcores; transformer core for SMPS |
| Korea TDK Co. | Bobbin thread; cup core, peaking coil; rotary transcore |
| Daewon Ferrite Co. | Antenna bar, ring core |
| Samhwa Enterprises Co. | Ferrite powder |
| Hard | |
| Taepyungyang Metal Co. | Hard ferrite magnet; magnetic powder |
| Korea Ferrite Co. | Hard ferrite magnet |
| Chahwa Electronics Co. | Plastic magnet<br>Magnetic powder |
| Saehan Media Co. Ltd. | Magnetic tape media |

## Diagram 7



Korea Taiyoyuden Co. dominates the ceramic capacitors market; Samhwa Electronics Co. is a distant second.

Of the total demand for advanced ceramics, 30% is supplied domestically. But in the important areas of ferrites and capacitors, domestic production is around 40% and 50% respectively of demand. This is facilitated by the fact that there exist plentiful supplies of domestically produced ferrite powders. All barium-ferrite required is produced domestically, more than 70% of soft-ferrite calcines are produced from steelmill by-products. Ferrite materials and related applications constitute the largest portion of the demand for ceramics, in such areas as hard and soft ferrites, magnetic recording heads, VCR's, computers, gamma ferric oxide powder, and raw calcines for soft and hard ferrites. In fact the ferrite sector, which is 45% of the total electronics market, is now virtually self reliant. Ceramic capacitors on the other hand, an area which developed early in Korea and still in high demand, is not in the same position, since Korea is entirely import dependent on raw materials for ceramic capacitors, piezoceramics, and semiconducting ceramics. Therefore some firms are developing technologies to blend premixed raw materials, and others have their own technology to produce individual oxide materials.

Finally, there is a measure of dissatisfaction[19] on the degree of R&D conducted by large firms on electronic parts such as capacitors and resistors and their vacation of domestic production of some components. Often it is the 600 medium or smaller firms which display aggressive strategies, entering segments abandoned by the conglomerates, but lacking the financial muscle and R&D facilities/equipment to conduct research. Recently, the Korea government legislated that 497 electronic parts and components must be made from Korean materials and processes. Moreover, 76% of all parts and components must be made in Korea by the end of the century, implying that imports of parts and components for the electronics industry must be reduced by 10% p.a. Another 219 items, including IC's, are prohibited to enter Korea from Japan. The result has been of great benefit to Korean suppliers of materials for DRAM's, ASIC's, multifunctional IC's, magnetic heads, multi-layer PCB's, pointless relays, ultra-microfilm capacitors, fine ceramic items and application capacitors. A very large budget of W225 billion to assist the Koreanisation of 4,500 electronic parts and components by 1991, (see Table 11 below) has been allocated by the government. Nevertheless, in the last two years all such regulations have been lifted in the context of free trade policy.

Table 11

| Product | Investment 1987 (billion won) | Monthly capacity (thousands) | Monthly shortage (thousands) |
|---|---|---|---|
| CRTs | 205.9 | 1 870 | 191 |
| Capacitors | 38.6 | 975 000 | 13 728 |
| Polyvaricons | 2.5 | 5 000 | 642 |
| Fixed Capacitors | 13.9 | 1 850 000 | 368 928 |
| Crystal vibrators | 3.1 | 33 500 | 7 650 |
| Mechanical tuners | 12.8 | 4 850 | 500 |
| Ferrite cores | 3.9 | 14 500 | 500 |
| Deck mechanisms | 4.0 | 2 540 | 50 |
| Rod antennas | 0.8 | 5 880 | 200 |
| PCBs | 18.1 | 339 $m^2$ | 91 $m^2$ |
| Diodes | 8.1 | 96 000 | 44 367 |
| Digitrons | 0.8 | 500 | - |
| TRs | 126.9 | 175 000 | 27,026 (surplus) |
| ICs | 188.0 | 224 210 | 747 (surplus) |

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[19] See 'A Special Issue on Electronic Materials in Korea', New Materials Korea, Vol 1, No 9, June 1988.

In terms of future strategic reorientation, the aim is to continue the high rate of growth in the electronics industry so that by the year 2000 electronics may constitute about 15% of GNP and hence constitute the largest Korean manufacturing sector. Nevertheless an important objective is to shift the industry towards higher value-added and technology-intensive sophisticated products so that reliance on consumer electronics is reduced and industrial electronics rises to a 40% share of the whole industry. This entails a massive R&D programme and expansion of domestic materials industries. And, in relation to the Koreanisation of the industry, the excellent existing research institutes are already offering large assistance to both small firms and the government. With the large role of research bodies such as KAIST, ETRI, KIETO and the Korea Electronic Industry Cooperative and MITI, most problems have already been identified, and need to be tackled in a coordinated effort. For example areas identified where small Korean firms lack expertise include: management of technology, moulding, chemicals, heat treatment, printing, painting, anti-corrosion, film manufacture and application and CAD technologies to design work.

## Specialty Chemicals[20]

The large mass production industries in Korea already use very large quantities of specialty chemicals. Not only is there a large domestic market for such materials but a growing international market in electrical, electronic, automobile, pharmaceutical products and agrochemicals. South Korea's supply and demand for major petrochemicals is shown in Table 12.

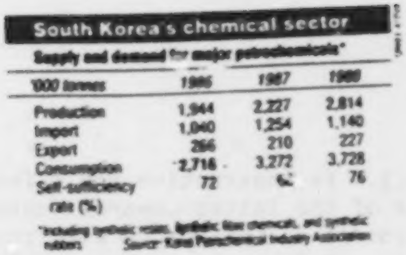
In 1987 Korean production of specialty chemicals was 20% of total chemical production, as compared to 90% in Switzerland, 70% in West Germany, and 50% in U.S.A., i.e. 1.86% of GNP as compared to 8-12% in IAC's. Korea is roughly at the same stage as Japan was in the late 1960's. It is widely predicted that there is scope for substantial growth in this area in Korea over the next 10 years. The Korean MITI has focussed on specialty chemicals as a central instrument in reducing the trade deficit and external dependence on Japan. Specialty chemicals account for 60% (in terms of cost) of Korean consumer electronics production.

Here again, there is strong government pressure for new technologies and new products, based as far as possible on local raw materials. Conglomerates in specialty chemicals have announced plans for expansion and other industries have shown an interest in entering the field. Nevertheless only 85 of the 756 Korean companies engaged in specialty chemicals production have R&D research capabilities, but this number is rapidly increasing. The Korean Association of Specialty Chemicals Industry (KASCI) has published a report commissioned from 100 Korean-based specialists, which predict that the value of the industry's output would rise from $300m. in 1988 to $12 billion by 2001, during which time over 100 products could be developed by Korea industry. Table 12.1 below shows some of the targeted areas of specialty chemical development over the next two decades.

## Liberalisation Measures and Free Trade Policies

The moves towards self-sufficiency in raw materials and components described above have,in the last 2 years, been increasingly accompanied by domestic liberalisation measures and free trade policies. In effect,Korean companies can import any amount they wish, from whatever source, of materials and components. Nevertheless, the efforts to develop domestic technological capabilities especially in electronics components and parts, continuous, due to difficulties of obtaining technology transfer from abroad, previously dominated by Japan.

Table 12



**South Korea's chemical sector**

Supply and demand for major petrochemicals*

| '000 tonnes | 1986 | 1987 | 1988 |
|---|---|---|---|
| Production | 1,944 | 2,227 | 2,814 |
| Import | 1,040 | 1,254 | 1,140 |
| Export | 266 | 210 | 227 |
| Consumption | 2,718 | 3,272 | 3,728 |
| Self-sufficiency rate (%) | 72 | 6[illegible] | 76 |

*Including synthetic resins, synthetic fibre chemicals, and synthetic rubbers. Source: Korea Petrochemical Industry Association

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20 New Materials Korea, Vol 1, No 7, April 1988.

Table 12.1

| 1988-1990 | 1991-2000 | 2001-2010 |
|---|---|---|
| Silicone activators, polymer activators, fluoro-activators | Bio-surfactants, reactive emulsifiers | |
| Refined vaseline, macadamia nut oil | UVA absorber, complex spherical powder, refined tar dyes | |
| Pollution-free water-soluble coatings, powder coatings, high-speed rotary press inks, corrugated cardboard, flexographic inks | Electric silver coatings and other speciality coatings such as electromagnetic interference coatings, conductive coatings, vacuum-deposition coatings, heat-resistant coatings and thermocoatings:<br>Offset printing inks, and new functional printing inks | |
| Master paper for graphic art, CT-NMR x-ray film, colour film and photographic paper, colour developer | Direct-positive colour films, high sensitivity colour films, films for semiconductors, photosensitive metal plates, films for astronomical/aerial photography | |
| Reactive dyes, anthraquinone disperse dyes and textile dyeing agents | Metal complex dyes, dyes for pressure-sensitive copying paper, dyes for heat-sensitive recording paper, ink jet recording dyes and heat-sensitive dyes | Speciality functional dyestuffs, pigments for electronic materials, solar energy conversion |

### 4.3.2 BRAZIL

#### Introduction

The South Korean case discussed in 4.3.1 is instructive and offers similarities to the Brazilian case, given the efforts of the latter towards fostering high-technology industries and the promotion of an indigenous electronics sector. Again it should be clear that the development of domestic high technology capabilities in the scientific, technological and manufacturing conditions of the 1990's will prove impossible without the close attention to the parallel and selective promotion of local advanced materials synthesis and processing capacity - with all the educational, institutional, measurement, evaluation and quality assurance policy foci that this entails. In fact we will make the strong claim that the survival of the Brazilian manufacturing industries, as for example, electronics and automobiles, both in domestic and world markets, will be in question in the 1990's, unless urgent and serious attention is given to close collaboration, and linkages, with high-quality suppliers of raw materials, parts and components, both in traditional but improved materials and in advanced functional ceramics, engineering polymers etc.

As table 13 shows, Brazil is in fact richly endowed with both traditional materials and several elements of the periodic table that enter new advanced materials categories. This offers vast potential to employ advanced processing technologies and quality control to upgrade traditional materials such as steel and aluminium to meet the more stringent requirements in manufacturing user industries domestically, regionally or globally. But, additionally, there are considerable opportunities for Brazil to establish substantial domestic processing and engineering capabilities in the extraction and fabrication of an array of advanced materials destined for functional and structural applications in downstream industries or the export market. As we have already mentioned in this paper, there is still enormous potential for improving the processing the properties of existing traditional materials. In fact, there is not much sense at present to castigate any material as 'traditional' in any meaningful sense. The 'advanced materials' of the next century will include new steel and aluminium alloys, as well as new cements. Hence, the acquisition or upgrading of advanced processing capabilities for the low cost, high quality processing and semi-fabrication of existing materials can confer considerable competitive advantages in the domestic and global market place of 1990's, and must under no circumstances be neglected by a rational materials policy in a developing and industrialising economy, especially one in the privileged resource position such as Brazil finds itself.

Moreover, the advantages of early entry and of cumulative learning by producing and using advanced materials are considerable. It cannot be assumed that economies will be able to easily enter in the future. Already considerable barriers in the acquisition of information and scientific knowledge in the development of superconductors have been erected internationally. This remark though should not be interpreted as implying that scarce resources should be devoted only to purely scientific research and experimentation. Necessary as frontier knowledge may be, if it not closely tied to processing capabilities and mechanisms for the incorporation of scientific knowledge into the industrial productive sphere in a supportive legal, macroeconomic and banking/venture capital environment, it can prove next to irrelevant for long term economic growth and industrialisation.

There is therefore a strong case to be made for the new Secretariat of science and technology in Brazil to give urgent priority to the formation of a national, integrated and consistent materials policy, not subject to the vagaries of macroeconomic stabilisation measures, budgetary fluctuations and political or bureaucratic change. For it is becoming increasingly clear, at least in the 'triad' markets of the U.S.A. Europe and Japan, that, in the new materials and manufacturing era, the foundations of technical change, competitiveness, export

Table 13: Brazilian production, reserves and reserve base for selected minerals

| | Mine Production 1986 | 1987 | Reserves | Reserve Base | Units |
|---|---|---|---|---|---|
| Bauxite | 6,224 | 6,500 | 2,800,000 | 2,900,000 | thousand m. tons |
| Beryllium | 42 | 50 | 360,000 (potential resources) | | short tons |
| Chromium | 315 | 300 | 9,000 | 10,000 | th. short tons |
| Columbium | 27,780 | 28,000 | 7,100,000 | 8,000,000 | th. pounds, content |
| Iron Ore | 129.9 | 134.0 | 15,600 | 17,300 | million long tons crude ore |
| Lithium | 42 | 40 | 1,000 | N/A | short tons, content |
| Magnesium | 81 | 80 | 50,000 | 70,000 | short tons, content |
| Manganese | 2,976 | 3,000 | 20,900 | 69,000 | th. short tons |
| Nickel | 25,400 | 30,000 | 900,000 | 4,700,000 | short tons, content |
| Niobium | N/A | N/A | 89% of world reserves | | |
| Quartz Crystal | N/A | N/A | Large | Large | |
| Silicon | 238 | 240 | Large | Large | th. short tons |
| Tantalum | 116 | 130 | 2,000 | 3,000 | th. pounds, content |
| Tin | 27,000 | 29,000 | 650,000 | 650,000 | metric tons/content |
| Tungsten | 800 | 800 | 20,000 | 20,000 | metric tons/content |
| Yttrium | 66 | 66 | 400 | 1,500 | metric tons of yttrium oxides |
| Zirconium | N/A | N/A | 24% of world reserves | | |

Source: U.S. Bureau of Mines, Mineral Commodity Summaries, 1988.

success, growth and employment are to be found in a healthy, knowledge intensive, high-technology materials and components sector. The acquisition of materials synthesis and processing capabilities has become an indispensable and critical component for technical change in an array of high technology industries including electronics and aerospace, and, for the speedy translation of scientific discovery into practical commercial application and end-product design for manufacture. Policy formulation and implementation in this area must be invested in a body which is able to cut across and coordinate between ministries and departments, since it involves the integration of science, technology, trade, industry and education policies. An additional requirement is that in targeting and setting priorities in scientific and technological research and development, industry, government and university cooperation is needed in order to identify and build upon domestic strengths, expertise and perceived technical and market opportunities. The potential location of IMAAC within Brazil may offer invaluable externalities, assistance and incentives in this area, as well, of course to many other developing economies, trying to come to terms with and establish the necessary, flexible and fast-responding institutions and policies enabling them to negotiate the complexity, discontinuity and uncertainty ushered in by the materials and information revolutions.[21]

## Materials Policies and Development Potential in Brazil

In this section we engage in a rather selective and brief discussion of recent Brazilian initiatives in new materials and the potential for development of existing and advanced materials sectors. Despite the considerable importance posed by traditional and emerging materials in Brazilian GDP and export structure, policy in this area was diffused in a multitude of government institutions until the mid-1980's. The establishment[22] of the Ministry of Science and Technology in 1985, brought with it central policy formation in the areas of science, technology, informatics, biotechnology but also the development of a "national policy for research, development, production and application of new materials...and other sectors of advanced technology" (Cassiolato, 1988). Since then, new materials have been identified as a priority area, with special importance attached to materials such as metals and metallic alloys, quartz (given Brazilian large reserves and its role in fibre-optics), advanced ceramics, engineering plastics, and composites.

Several agencies of the Ministry of Science and Technology (CNPq, FINEP, INT and SEI) together with leading Brazilian scientists were charged with the responsibility of drawing a preliminary set of proposals and plan of action on new materials which went for approval to the Government. The National Commission on Materials, set up a 2-year plan of action on materials, which was approved by the Government. Most of the proposals were in fact subsequently implemented, at least on the expenditure side. Nevertheless, policymaking in these areas has been suffering as a result of the fortunes of the Ministry of Science and Technology, which, since its inception, was fused into the Industry and Trade Ministry, lessened in importance as a lower rank Secretariat, and then more recently transformed into a Ministry again. Following the recent elections and the inauguration of the new President, in mid-March 1990, the Ministry was transformed back into a Secretariat, but with direct access to the President, and a prominent physicist and rector of the University of Sao Paulo was appointed to head it. A new head was also appointed for the Secretariat's most important body, the National Council for Scientific and Technological Development (CNPq), with a promise of increased funding. But clearly such uncertainties and vicissitudes in government policy towards a critical Ministry and its associated bodies can prove disasterous for the formation and implementation of a coherent strategy in science, technology, and the materials field, and is in marked contrast to the long-term planning, single-minded and unwavering pursuit of materials strategies in Japan, and increasingly in South Korea.

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[21] See: L. Kaounides, 'Advanced materials and Primary Commodities', April 1989, Chpt 5, and Recommendations of Final Report, Expert Group Meeting, UNIDO, Vienna, 1989, op.cit., PPD. 116 (SPEC.), 24th May.

[22] For details of the materials situation in Brazil and related policies in recent years see:

José E. Cassiolato: 'Policies for newly industrialised countries: the case of Brazil, ATAS Bulletin, Issue No 5, May 1988.

R.C. Villas-Boas, 'Brazils National Policy on New Materials', UNIDO, IPCT.57(SPEC.), 14 April 1988.

H.M. Martins Lastres, 'The Impact of Advanced Materials on World Development', Advances in Materials Technology, MONITOR, UNIDO, Issue 16, January 1990.

At the same time though, excellent work[23] has been accomplished by two innovative bodies in the materials field, the Secretariat of New Materials set up in 1987, located within the Ministry of Science and Technology (now itself a Secretariat) and, until recently under the Office of the President, and, over the last three years, by the Nucleus for the Study and Planning in New Materials (NMAT), set up in 1986, conveniently located within the vast scientific, technical and metrology/testing infrastructure of the National Institute of Technology (INT). Such bodies comprising of multidisciplinary teams of scientists, engineers and economists are indispensable in monitoring scientific and technological trends, accessing, assimilating and assessing rapidly evolving materials information and data, and offering guidelines to industry and government. Such bodies operating as national think-tanks and/or strategic planning and policymaking instruments in materials research, and in technological and industrial development are becoming a necessity across the differentiated array of developing economies and can serve as nodal points in a regional and international materials network under the umbrella of IMAAC. Not only is the Brazilian example to be emulated elsewhere, but the importance of a semi-autonomous, multidisciplinary, competent and flexible materials secretariat and associated study groups or think-tanks will become even more evident within Brazilian industry, scientific community and government in the 90's. It should therefore be further strengthened. The new administration has, since March 1990, disbanded the existing forms of secretariats in high technology areas, except the one in informatics, and brought them under one roof in a new department. It is too early to evaluate the benefits or consequences of such a move.

## New Materials and Processes

Due to a combination of high grade, major world reserves in several minerals such as bauxite, iron ore, chromium, columbium, quartz, niobium, titanium, berillium and rare earths, together with considerable existing processing and engineering metallurgical strengths, high-calibre research institutes and laboratories and frontier university scientific expertise, Brazil could potentially emerge as a major force in world production and trade in new and advanced materials and components.

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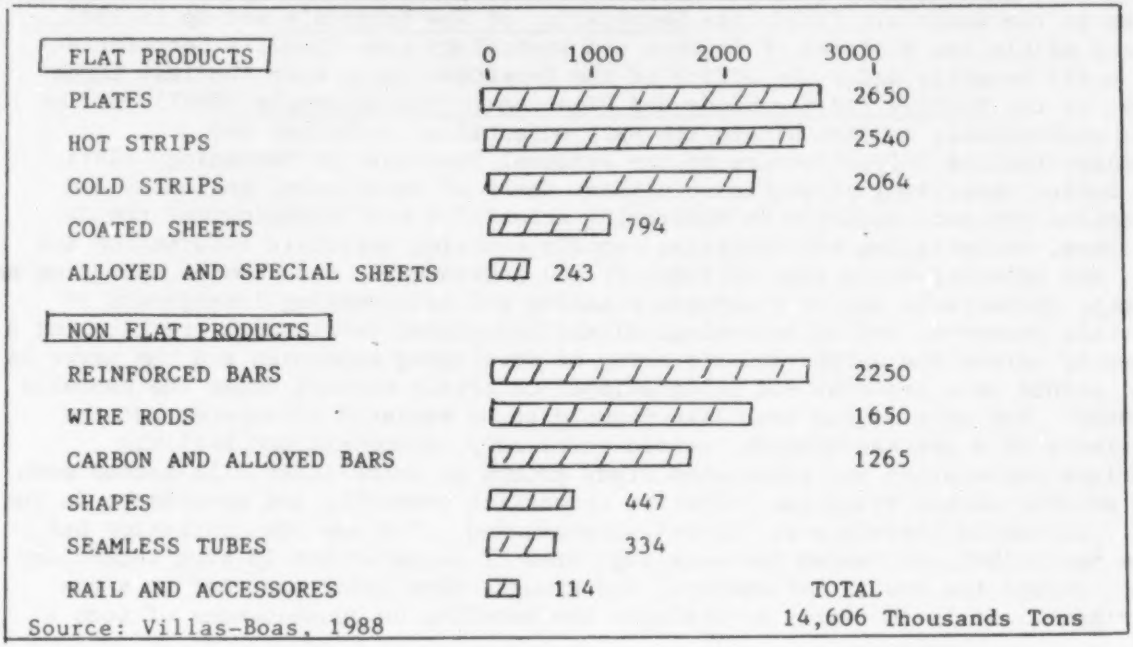
[23] See, for example, Helena Maria Martins Lastres, coordinator, et.al., "Novos Materiais, Capacitacao e Potentialidades Nationais em P&D", INT/NMAT, Riode Janeiro, 1988, which contains a comprehensive coverage of Brazilian institutions, personnel and research programmes in new materials, relevant companies etc. And, several other monographs and studies on trends in materials science and technology. In fact NMAT provided the analytical and research input that went into the formation of a national materials policy and the 2-year plan formulated by the National Commission on Materials. Both the NCM and NMAT were established in 1986.

In the area of metals and advanced alloys, tremendous potential exists in developing new metal alloys entering into high performance applications in an array of high technology industries, such as aerospace, electronics, petrochemical plant, nuclear, automobiles and others. Already, the steel industry, which dominates the Brazilian metals sector, engages in controlled rolling of high strength low alloy (HSLA) steels, continuous annealing to produce high strength cold rolled steel, and speciality steels, as shown in Figure 9 below. Several Brazilian enterprises also engage in research and production of several advanced alloys. A large number of government research centres and university physics, metallurgical and materials departments (e.g. UFRG, USP, UNICAMP, UFRJ/COPPE etc.) also conduct research on sophisticated new materials, metals and aadvanced metallic alloys entering a range of sophisticated industries, illustrated in matrix form in Diagram 8.

Figure 9: Volume and variety in the Brazilian steel industry output, 1985



Source: Villas-Boas, 1988

Demands emanating from advances in high technology industries have led to the development of several new alloys, with some emphasis, appropriately for Brazil, on Niobium alloys. Table 14 shows the potential for the development of advanced alloys entering high technology industries in Brazil.

Quartz crystal is essential for making piezoelectric filter devices and oscillators that provide single frequency signal sources, both of which are widely used in a large variety of communications and instrumentation purposes. There are limited resources of quartz crystal for direct electronic and optical use, so that cultured quartz crystal (utilising lascas as feed material) is now gaining acceptance as an alternative material. Japan remains the world leader in growing cultured quartz crystals, due to lower cost and the fact that it is a major producer of electronic components which use these crystals. The U.S. relies entirely on Brazilian natural quartz as feedstock in growing cultured quartz and for a few direct applications. Brazil possesses most of world reserves in crystal quartz, and is a major supplier of quartz flakes to the world cultivated quartz industry. The export prices of quartz flakes averaged about $2 a kgm, whereas synthetic quartz crystal and silicon monocrystal fetched $40 and $400 per kgm respectively. The obvious development potential of the sector and the acquisition of cultivated quartz technologies through licencing and joint ventures must be integrated with the fostering of domestic electronics, telecommunications and opto-electronic capabilities. There is already some domestic capacity in the production of cultivated quartz

Diagram 8: Industrial Applications of New Metallic Materials

| MATERIAL |  |  | AEROSPACIAL | NUCLEAR | MILITARY | AUTOMOBIL | STEEL MAKING | CHEM.+PETROCH. | ELECTRO-ELCS. | BIOMEDICS | PETRO-EXTRACT. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CONVENTIONAL | STEELS | special | ● | ● | ● | ● | ● | ● |  |  | ● |
|  |  | ultra-high resis. +tenacity | ● |  | ● | ● | ● | ● |  |  | ● |
|  |  | stainless | ● | ● | ● |  | ● | ● | ● |  |  |
|  |  | recovered |  | ● | ● | ● | ● | ● |  |  | ● |
|  |  | ultra-high purity |  |  | ● | ● | ● |  |  |  |  |
|  |  | roll.control. microstructure |  |  | ● | ● | ● |  |  |  |  |
|  |  | microalloied |  |  | ● | ● | ● | ● |  |  | ● |
|  | ALLOYS | Al | ● | ● | ● | ● |  | ● | ● |  | ● |
|  |  | Mg | ● | ● | ● | ● |  |  |  |  |  |
|  |  | Ti | ● |  | ● |  |  | ● |  | ● | ● |
|  |  | Fe | ● |  | ● |  |  | ● |  | ● |  |
|  |  | Sn |  |  |  | ● |  | ● | ● |  | ● |
|  |  | Cu |  |  |  |  |  |  | ● |  |  |
|  |  | Ni | ● | ● |  |  |  | ● | ● | ● | ● |
|  |  | Others |  |  |  |  |  |  | ● |  |  |
|  | Superalloys |  | ● | ● | ● |  | ● | ● |  |  | ● |
|  | Cast Iron |  |  |  | ● | ● |  |  |  |  |  |
| STRATEGIC | Zr |  |  | ● |  |  |  | ● |  |  |  |
|  | Be |  |  |  | ● |  |  |  |  |  |  |
|  | RareEarths |  |  | ● | ● |  |  |  | ● |  |  |
|  | Refractories |  | ● |  | ● | ● | ● | ● | ● | ● |  |
|  | Nuclears |  |  | ● |  |  |  |  |  |  |  |
|  | Fiber Reinforced |  | ● |  | ● |  |  |  |  |  |  |
| ADV | Superconductors |  |  |  |  |  |  |  | ● |  |  |
|  | Amorphous Met.Alloy |  |  | ● |  |  |  |  | ● |  |  |
|  | Memory Effect Met.Alloy |  | ● |  |  | ● |  |  | ● | ● |  |

INDUSTRIAL SECTOR

**Source:** R.C. Villas-Boas, Brazil's National Policy on New Materials, 1988

**Table 14:** Metals and Special Alloys - possibilities of development in Brazil

| *Materials* | *Industries* |
|---|---|
| (a) structural steel with high resistance (main elements — Cr, Ni, Cu, Ti, Mo, Co, Al, Mn, Nb, V and rare earth) | — aeronautics<br>— petroleum<br>— armaments<br>— automotive |
| (b) revested steel | — automotive |
| (c) Al alloys | — aeronautics |
| (d) Cu alloys (with Si, Sn and Cr, or Si, Al and Co) | — microelectronics |
| (e) Ti alloys (with Al, Sn, Zr, Mo, Nb, Si) | — aeronautics |
| (f) superalloys—resistant to corrosion and high temperature | — aeronautics<br>— armaments |
| (g) Be alloys (with Cu, Al, Co, Ni) | — aeronautics<br>— electronics<br>— armaments |
| (h) refractory metals and alloys (Ta, Mo, W, Nb, Ti) | — electronics<br>— special equipment |
| (i) Nb alloys (with Ti, Sn, Zr, Ga, Al, Ca) | — electronics<br>— superconductor |
| (j) rare earth | — electronics<br>— siderurgy |
| (k) amorphous alloys | — electronics |

**Source:** Jose E. Cassiolato, ATAS Bulletin, Issue 5, May 1988, p.138.

oscillators, and optical fibres (through CPqD-Telebras developed technology). Even though Brazil is a major world producer of metallurgical grade silicon, mainly from quartz, it does not produce electronic grade or solar grade silicon.

In advanced ceramics, the domestic market recently stood[24] at $300 million, with 80-90% held by domestic companies producing substrates, insulators, ferrite capacitors, and piezoelectric components. About 25 Brazilian companies produce advanced ceramics, and a major part of the market is taken up by multinational companies such as NGK (e.g. alumina substrates), Bosch, Coors, Thompson-CSF (barium titanite capacitors), Rohm (barium titanite capacitors and resistors), Constanta-Ibrape (ferrites and resistors), Pirelli (fibre-optics) and Cornig. National firms are mainly small to medium, in the process of expansion and consolidation, such as ABC-EXTAL (fibre-optics), V.C. Varistores e Balestro, Thorthon and others. Two of the national firms are producing ceramics for the electronics sector, seven for thermo-mechanical applications, and one for optical fibres.

In addition, there is considerable activity in the production of advanced ceramic raw materials and special powders, such as alumina and zirconia. Raw materials and powders research is conducted, additionally, in a number of universities and research institutes, such as IPEN, UNESP, and others. In fact frontier research on advanced ceramics is conducted by several leading scientists in a number of universities, the most important being the Department of Materials Engineering of the Federal University of Sao Carlos. Figure 10 illustrates the main institutions and lines of ceramics research conducted in Brazil.

### Advanced and improved traditional materials in Brazilian high-tech and manufacturing industries under world market competitive conditions in the 90's.

From this very brief discussion it should be evident that Brazil has substantial and existing strengths in natural resource endowments, processing and semi-fabricating capacity in a range of traditional and new advanced materials technologies, large and increasing domestic markets in the form of high technology industries utilising a vast array of sophisticated materials and components and high-powered research institutes and university departments in frontier science. 'Traditional' materials capabilities can be strengthened, with a strategy of moving to higher added value fabrication of metal alloys and specialties required both in mass production and high tech industries. Special attention could be given to coatings, surface treatment, surface and interface science, adhesives, bonding and joining technologies as well as near net shape manufacture in industry. Moreover, such industries will be subject to irresistable technological and organisational pressures for closer links and computer-aided interfacing with their customers in industry to facilitate innovation and design, component simulation and materials optimum selection from a common database, specifications and quality control, and ability to respond to the specific needs of their customers for a group of properties (rather than a specific material) in a concrete application. As in the case of South Korea, it is likely that Brazil will find it necessary to promote domestic self reliance in a range of raw materials and functional components and parts destined for domestic high technology manufacturing, aerospace and military applications.

Materials strategy is inseparable from the specific forms that the transition of Brazilian manufacturing industry is taking in the adaptation of emerging 'best-practice' Post-Fordist automation technologies and associated organisational change in production.[25] Little evidence exists, but there appears to be a piece-meal,

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[24] Anuário Brazileiro De Ceramica, 1989, p.76.
See also Tables 15 and 16 for breakdown of the Brazilian markets for electronic and magnetic ceramics around 1988-89.

[25] See A.G.A. Filho, R. Marx, M. Zilbovicius, "Fordism and New Best Practice: Some Issues on the transition in Brazil"

selective and restricted application of (domestically adapted) flexible manufacturing technologies and J-I-T. Of course it is not to be expected that a wholesale adaptation of Japanese practices and industrial relations would be possible or desirable in a different social formation, exhibiting different historical experience, labour/management relations, trade union strengths and so on. Export orientated industries have moved to more flexible methods of manufacture, and some car component suppliers have began to employ FMS and CNC, but the diffusion of microelectronics based automation technologies in Brazilian industry is still in its infancy. Car manufacturers are pushing inventory control to their suppliers, enforcing JIT adaptation by the latter. Nevertheless, despite the increasing pressures on component suppliers for JIT, quality control and adaptation of statistical quality control methods as well as for faster and more irregular deliveries, the car industry has not yet fully moved towards the reduction in the number of suppliers and the cultivation of longrun, stable contracts with them. This of course does not mean that world market pressures and imperatives imposed by the foreign design and decision making centres will not lead to increased diffusion of these techniques in the 90's. The piecemeal and selective adaptation of Post-Fordist best practices in Brazilian manufacturing may, in fact, be the only possible, rational and efficient solution in the current socio-economic and political circumstances. But the question remains as to whether this will be enough to maintain competitive advantage and the survival of major portions of Brazilian manufacturing in the 90's. To what extent, for example, are a multiskilled labour employed as a resource, or, long-run supplier-producer relationships necessary for efficient production and sustained patterns of innovation in the future, as Japanese and other foreign counterparts move even faster ahead, in order for segments of Brazilian manufacturing to remain competitive and retain market share in the 90's?

It must be pointed out that policies viz-a-viz advanced materials cannot be separated from the overall framework and experience of Brazilian policies towards high technology industries, and the fostering of national segments of advanced manufacturing technologies and output, as in computers. The subject matter cannot be dealt with in detail here, but the issues of early entry, protection of 'infant industries' and consequent liberalisation, the need and forms of access to foreign technology in the form of joint ventures and licencing agreements, the role of the private vs public sector, human resource development and training incentives, selectivity, and the need for a sustained long-run policy and committed resources towards science and technology research and industrial development, will also encompass the materials sector. In fact the speed of technical change and shifts in the science frontier would make it even more imperative (as S. Korea has found out) to seek foreign technology in a range of high-tech industries, and especially in the materials and components field, in the 90's. Here the legal framework, protection of intellectural property rights, cross border freedom in the transfer of technology, and the provision of maintenance, support and repair services would all play a critical role in attracting foreign capital and facilitating technology transfer from foreign MNC's. The existence of a minimum mass of indigenous scientific and technological expertise and innovation potential together with opportunities to access domestic markets, and negotiating skills build up over the years, may, in the 90's offer greater attractiveness of Brazil to foreign capital for joint ventures in microelectronics and materials branches. But, it must also be borne in mind that the combined effect of microelectronics and advanced materials production and use, would enhance the complexity and importance of a

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R. Lima, "Implementing the Just in Time Production System in the Brazilian Car Component Industry"
R. Carvalho and H. Schmitz, "Fordism is Alive in Brazil"
All in IDS Bulletin, Vol 20, No 4, October 1989. And: J. Humphrey, 'Adapting the Japanese Model to the Brazilian Experience', IDS, April, 1990, mimeo, H. Schmitz and R. de Quadros Carvalho, Automation and Labour in the Brazilian Car Industry, IDs Discussion Paper, December 1987, No. 239.

**Table 15:** Brazilian Markets for Electronic Ceramics, 1989

| FUNÇÃO | COMPONENTE | MATERIAS-PRIMAS | | PRODUTO FINAL |
|---|---|---|---|---|
| | | t/ano | US$X$10^6$/ano | US$ X $10^6$/ano |
| ISOLANTES | VELAS DE IGNIÇÃO | 1500 | 1,5 | 55 |
| | SUBSTRATOS P/CI$_s$ | 7,5 | 0,01 | 0,6 |
| | RESISTORES E OUTROS * | 300 | 0,3 | 12 |
| FERROELÉTRICOS | CAPACITORES CERÂMICOS | 160 | 1,2 | 15 (FABRICAÇÃO NACIONAL)<br>5 (IMPORTAÇÕES) |
| | CAPACITORES MULTICAMADAS | nd | 0,4 | 8 (IMPORTAÇÕES) |
| SEMICONDUTORES | TERMISTORES NTC | 5 | 0,35 | 1 |
| | TERMISTORES PTC | 2,5 | 1,4 | 4 |
| | VARISTORES | 24 | 0,6 | 12 |
| PIEZOELÉTRICOS | TRANSDUTORES E OSCILADORES | nd | nd | nd |
| TOTAL | | - | 5,8 | 112,6 |

* DIODOS, POTENCIÔMETROS nd = não detectado

Source: M.M. Veiga et.al., 1989

**Table 16**: Brazilian Market for Magnetic Ceramics, 1989

| COMPONENTE | MATÉRIAS-PRIMAS |  | PRODUTO FINAL |  |
|---|---|---|---|---|
|  | t/ano | US$ X $10^6$/ano | t/ano | US$ X $10^6$/ano |
| FERRITES DURAS ("HARD") | 3800* | 0,8 | 3600 | 7,5 |
| FERRITES MOLES ("SOFT") | 5000*** | 1,5 | 5000** | 15 |
| T O T A L |  | 2,3 |  | 22,5 |

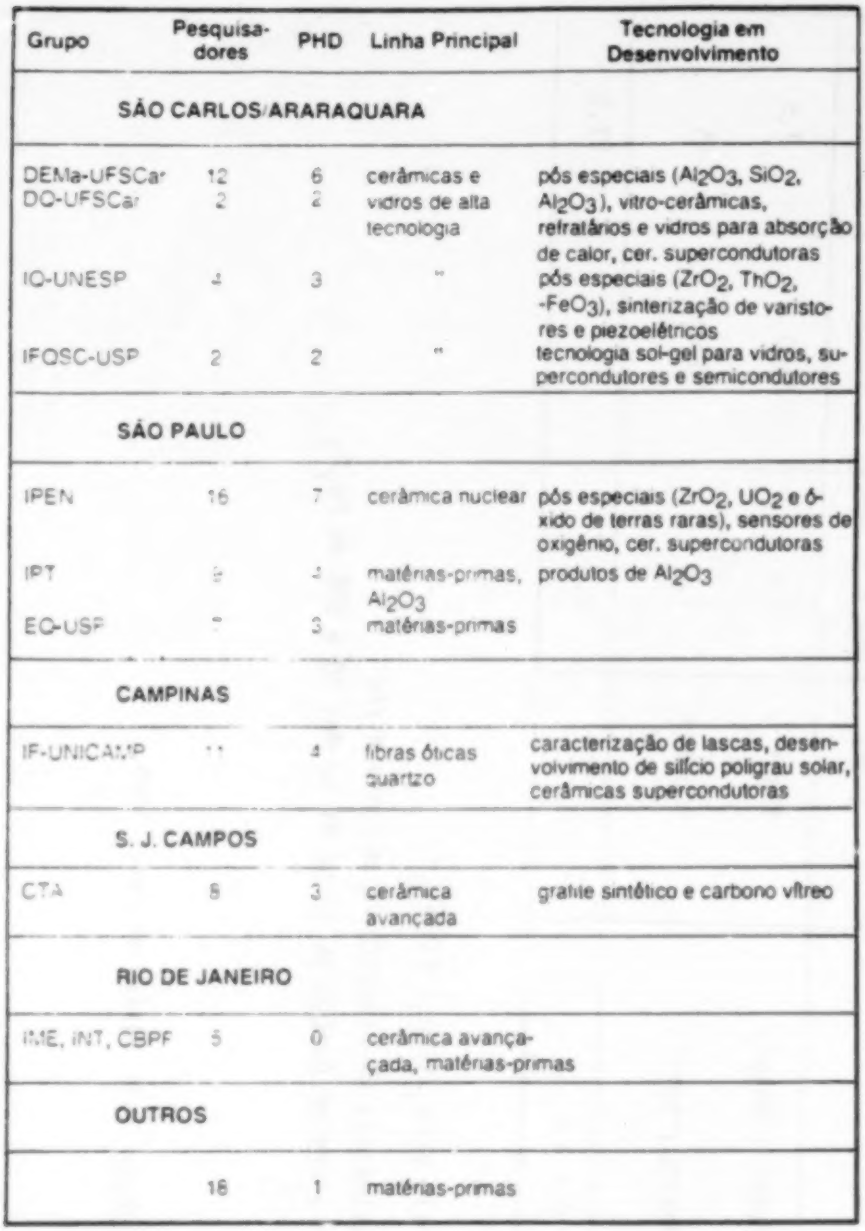
* ≃ 17% $BaCO_3/SrCO_3$; 83% $Fe_2O_3$

** ESTIMATIVA DE FERRITES DE Mn/Zn e Ni/Zn

*** 30 a 40% DE ÓXIDOS DE Zn ou Ni ou Mn; 70 a 60% de $Fe_2O_3$

**Source**: M.M. Veiga, et. al., 1989

Figure 10: Ceramics Research at Brazilian Institutions



| Grupo | Pesquisa-dores | PHD | Linha Principal | Tecnologia em Desenvolvimento |
|---|---|---|---|---|
| **SÃO CARLOS/ARARAQUARA** | | | | |
| DEMa-UFSCar<br>DQ-UFSCar | 12<br>2 | 6<br>2 | cerâmicas e vidros de alta tecnologia | pós especiais ($Al_2O_3$, $SiO_2$, $Al_2O_3$), vitro-cerâmicas, refratários e vidros para absorção de calor, cer. supercondutoras |
| IQ-UNESP | 4 | 3 | " | pós especiais ($ZrO_2$, $ThO_2$, -$FeO_3$), sinterização de varistores e piezoelétricos |
| IFQSC-USP | 2 | 2 | " | tecnologia sol-gel para vidros, supercondutores e semicondutores |
| **SÃO PAULO** | | | | |
| IPEN | 16 | 7 | cerâmica nuclear | pós especiais ($ZrO_2$, $UO_2$ e óxido de terras raras), sensores de oxigênio, cer. supercondutoras |
| IPT | 9 | 4 | matérias-primas, $Al_2O_3$ | produtos de $Al_2O_3$ |
| EQ-USP | 7 | 3 | matérias-primas | |
| **CAMPINAS** | | | | |
| IF-UNICAMP | 11 | 4 | fibras óticas quartzo | caracterização de lascas, desenvolvimento de silício poligrau solar, cerâmicas supercondutoras |
| **S. J. CAMPOS** | | | | |
| CTA | 8 | 3 | cerâmica avançada | grafite sintético e carbono vítreo |
| **RIO DE JANEIRO** | | | | |
| IME, INT, CBPF | 5 | 0 | cerâmica avança-çada, matérias-primas | |
| **OUTROS** | | | | |
| | 16 | 1 | matérias-primas | |

Source: Maria Tereza G. Duarte, Inf. INT. v.19, no.38, 1987, p.9

whole network of maintenance, support and repair services and skills. On top of this one may add the necessity of high technology recycling and waste disposal industries developed in parallel with the new high-technology industries and generalised use of more complex materials in complex products.

### 4.3.3 Advanced Materials and the NIC's: South Korean and Brazilian early 'entry' into advanced materials high-technology in the emerging post-Fordist industrial paradigm.[26]

The discussion above, albeit not comprehensive, of the two important NIC's and their evolving strategies and experiences of early entry into advanced materials research and production, has highlighted several issues. It must be borne in mind, of course, that the two socio-economic formations are products of vastly different historical experiences and resulting institutions, forms of labour and work organisation, management practices, industrial relations, domestic mechanisms for the conduct of pure and applied scientific research and its transmission into technical and commercial application, state support and protection of nascent high-technology industries, trade regime and sets of domestic price controls, subsidies and incentives. Such differences, including policies towards the acquisition of foreign technology, have meant, for example, wide variation in domestic innovational capabilities and dynamism, and, in the adaptation of new manufacturing best practice technologies. Both these factors will be critical for competitive survival in the 90's, especially given the trend in both countries for more openness and integration into the world market.

As S. Korea's industrial structure has been shifting towards more sophisticated, higher value-added, capital intensive production, in response to both rising domestic land and labour costs and competition from low wage neighbouring economies at the lower end of the market, it has relied extensively on foreign technology, through licensing agreements and other formal mechanisms facilitating a net transfer of technology to Korea, especially in electronics. Nevertheless, access to foreign technology, especially to the latest and more sophisticated technologies, cannot be assured in the 90's, given an increasing reluctance of U.S. and Japanese corporations to provide even 'outdated' technology to potential competitors. As we have seen the need for foreign technology has also been the case in advanced electronic ceramics, with all the attendant difficulties of ensuring continuity and timely supply, especially from potential competitors. This lack of domestic R&D and technological capabilities in advanced materials and high technology, more sophisticated industrial branches, is emerging as a critical impediment to industrial success in the 90's. And, moreover, it is part of a more widespread and dangerous lack of domestic capabilities in technical change, product innovation and design. As the economy is moving towards greater liberalisation of domestic markets and opening up to the fierce and coercive forces of the world market, where competition in the 90's will increasingly take place in terms of technology, knowledge-content, innovation, design and quality, these serious deficiencies can decimate domestic and export market shares in many branches. Already[27] the consumer electronics (see Diagram 9) sector has stumbled due to high domestic costs, protectionism in the U.S. and EC markets, for compact disc players and TV sets, and competition from other low-wage economies. In the medium run, a degree of protection of the domestic market and the existence of new markets of Eastern Europe and S.E. Asia can cushion the effect on the producers of relatively unsophisticated standardised commodities. But clearly, new strategies, management practices and manufacturing technologies are required for S. Korea's companies which have hitherto enjoyed success in mass-production and assembly of low-cost commodities and are now slow to adapt to the new market and manufacturing realities. In response to some of these pressures, some Korean companies are already locating in neighbouring lower wage economies, and establishing production facilities in the protected markets of the U.S. and E.C., where, of course, they come up against local content requirements.

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[26] For the role of new materials in the transition to post-Fordism, see
L. Kaounides: 'Advanced materials, the Restructuring of Industry and the Third World', IDS Discussion Paper, May 1990, Ch.3, section 3.1.3.
and L. Kaounides and Robin Murray: 'New Materials and Post-Fordism', Cambridge Journal of Economics, (forthcoming)
New materials technologies and information technologies are increasingly merging, and are capable of acting as radical generic technologies affecting the whole productive base, rebuilding the capital stock and associated infrastructure. For the role of materials on the rhythm of fixed capital formation and secular periods of acceleration or retardation of economic activity, and the emergence of a new industrial and socio-institutional paradigm see Kaounides, May 1990, Ibid, Ch.3., section 3.1.4. This aspect has been almost completely missed in the long-wave literature.

Thus, the necessary transition of a newly industrialising economy towards more technological sophistication and the adaptation of new best practice manufacturing technologies, will increasingly bring to the fore the inescapable needs to acquire domestic R&D, and technological and engineering capacity, as well as new forms of supplier-user collaboration, design, product renewal and quality control capabilities, and new patterns of work organisation, management practices, and flexible automation technologies. The acquisition of a critical mass of, and a measure of independence in domestic R&D, technological innovation, design and quality capabilities is central to industrial strategies for the 90's. But no economy or industry can be scientifically and technologically self-reliant, especially in the fast changing technological circumstances and resulting cross-border transfer of technology, networking and collaboration agreements now prevalent in the world economy.[28] Hence, it is this difficult balance between a minimum level of domestic research and technology dynamism and reciprocal access to foreign up to date technology that will exercise both firms and governments in S. Korea, Brazil and many LDC's in the 90's. A minimum critical mass of domestic research and technological competence is necessary not only for autonomous innovation, but also in terms of fostering an ability to absorb and keep ahead in a global environment of fast evolving scientific and technological change, through formal and informal linkages and agreements with laboratories and technology leaders abroad. Without a measure of independence in in-house technology and management and negotiating skills, then successful technology transfer or shared development is unlikely either to be attractive to foreign companies, or, assimilated and improved upon domestically.

Given the pervasive and revolutionary character of new materials and information technologies and their systemic diffusion across the whole of the manufacturing base, associated infrastructure and management practices, the institutional mechanisms and industry-university-government linkages facilitating the translation of pure and applied research into technical advance and commercial application becomes an issue of central importance across both IAC's, NIC's and other LDC's at this transitional conjuncture. At several points in this paper we have stressed the necessity of linking the pure science research with engineering and processing capabilities in new materials, and the close integration and collaboration between materials and component design and end users in industry. This is but an important subcomponent of the more general, but nevertheless very concrete, problem of enhancing the channelling of pure and applied R&D into the industrial sphere. As the materials and information revolutions increasingly merge and take a foothold in the institutions, management practices and productive base of IAC's, it is those economies that more readily incorporate and channel new scientific insight and new technologies into practical commercial application that will gain competitive advantage, and it is here that Japan is supreme. Thus the question of 'early' entry by NIC's and other LDC's into advanced materials and high-technology industries, is not merely connected to the acquisition of domestic technological capabilities, not only related to the need to access up to date foreign technology, but also to the creation of those domestic structures, institutions, consortia and government support schemes that facilitate the spread of new technologies into the industrial sphere. Similar difficulties of course are prevalent in IAC's, but the problem is more acute in LDC's where such mechanisms and linkages exist, if at all, in more rudimentary forms and must therefore be addressed urgently and coherently in the early 90's. Otherwise, the difficulties of entry and effective participation once such new technologies have taken hold in the institutions and industries of IAC's, may be insuperable for most LDC's, including the NIC's

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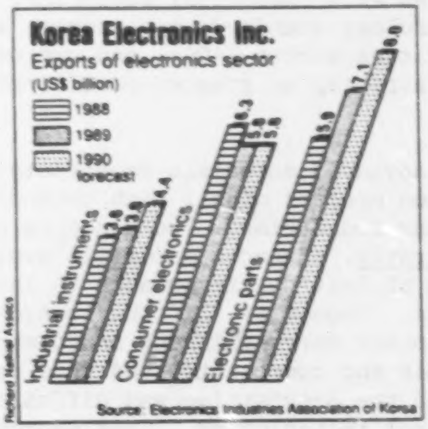
[27] South Magazine, May, 1990, pp42-43.

[28] See L. Kaounides: 'International Business Strategies and Trends in High-Technology: The Case of advanced materials', IDS, May 1990 (Chapter in book, P. Daniel (ed.), forthcoming).

There remains the exceedingly difficult issue of the degree, instruments and duration of fostering and building up of domestic research and high-technology activities and national firms. What we wish to point out here, is the need to reconsider traditional approaches to this matter in the light of the scientific and technological circumstances likely to prevail in the 90's. However successful such 'infant industry' policies may have been, and judicicus the mix of public vs private sector involvement, erecting protective barriers around national advanced materials firms and preventing the free flow of technology across national borders, whether it be for military or commercial reasons, is likely to be self-defeating in the long-run. Access to the fast evolving materials science base, advanced processing methods and latest innovations and up to date technologies from abroad is now-a-days essential, and must complement national and domestic firms' in-house capabilities both in materials and information-related high technology.

Diagram 9



Thus, it is debatable as to whether the hitherto severely restrictive practices of Brazil in the area of technology inflow, however noble the motive of 'enforcing' domestic research and technological competence, can remain viable in the 90's. Although this policy did achieve a degree of success in same areas, e.g. fibre optics, further restrictive 'containerisation' of Brazilian high technology firms is likely to be detrimental to sustained innovation, consolidation of the advanced materials early entry gains, and future competitive position. The obverse of opening up to technology flows is that in the absence of a critical mass of domestic processing/engineering technologies and linkages to industrial application, a new materials invention that might occur in Brazil, S. Korea or India may be successfully first incorporated in a new process or product and commercialised abroad, as several IAC's are currently experiencing.

Brazil is in fact beginning to debate the merits of and move towards more domestic competition, deregulation and liberalisation of both industry and the economy, and greater openness and reform of the trade regime. As in the case of Korea, this implies that manufacturing industry must begin to adapt to the chill winds of world market competition. Domestic R&D, technological innovation, product design and quality control will soon have to be confronted. Firms engaged in world market exports, e.g. in metals, already offer high quality products, but many protected industries face very urgent needs to upgrade quality and meet world standards. And, firms in some industries, e.g. ferrous and non-ferrous metals production, have used licensing, joint-ventures and other agreements to keep up to date with technology advances. But together with metals industries abroad, they increasingly realise that they need to acquire multimaterials capabilities, both in-house and through acquisitions, mergers, joint ventures and other collaboration agreements with firms aboard. The enhancement of the multidisciplinary research competence of materials producers and the need to employ an array of complex scientific and technological expertise across many fields, such as computer science, microelectronics, materials and so on in the development of high-technology products, as in aerospace, implies the need for greater university, government lab and industrial research collaboration and linkages. Unfortunately such linkages are currently unsatisfactory, especially in meeting the research needs of small to medium firms which do not possess the resources required to conduct in-house R&D. As in IAC's, the state provision of centralised facilities in expensive instrumentation and equipment required for quality control, characterisation, performance evaluation measurements and experimentation seems inevitable. Not even very large firms can master fully the financial resources, the complexity of inter-disciplinary scientific and engineering inputs or the exceedingly expensive laboratory facilities involved in materials and microelectronics related high technology innovation. Cooperation, collaboration, networking, formation of consortia, joint R&D of new technologies with commercial potential, and access to government research facilities and metrology/standards assistance, are all current mechanisms for overcoming such difficulties across IAC's, and are even more necessary in economies such as Brazil aspiring to greater participation in the world economy.

In sum: Improved traditional and new advanced materials constitute essential inputs in the functioning and innovation process of all high technology industries and an increasing array of manufacturing industries. Two elements of this proposition merit further comment. Firstly, advanced materials synthesis and processing capacity is a priority area of critical importance to innovation and competitiveness of high-tech industries. Economies shifting towards sophisticated, science-based industries and products place very stringent and demanding performance characteristics on materials and components, and thus rely on solutions emanating from materials industries and the acquisition and diffusion of appropriate metrology and quality control technologies. Thus national strategies towards high-technology and the restructuring of the industrial structure are inconceivable without prior elaboration of appropriate national strategies in advanced materials and components design, fabrication and manufacture in close collaboration with end-users. The acquisition or further strengthening of nascent advanced materials synthesis and processing capacity within the national economy, implies close attention to the multi-disciplinary educational and research programmes, advanced instrumentation technologies, metrology and standards assistance to industry, the development of materials property data bases, testing and quality control, and, technology transfer programmes and local training clauses, that must accompany such strategies.

Secondly, traditional materials with vastly improved properties and employing advanced manufacturing and processing techniques provide inputs throughout manufacturing. The 1990's will witness the more widespread diffusion of IT across the industrial base and the adaptation of new best-practice management, work organisation and microelectronics based automation technologies in manufacturing with variations in national contexts. Materials selection, tailorability and use already forms an integral part of end product design and manufacturing path, thus providing much of the basis for flexibility, innovation and competitive advantage in post-Fordist industrial organisation. Increasingly computerised materials property data bases will provide linkages between materials producers and users in industry within economies and across diverse sources internationally, for CAD/CAM efficient materials selection, prototype simulation and manufacturing path set-up, thus speeding up product renewal and offering a multitude of design and manufacturing options. Design for manufacture and concurrent manufacture are emerging as core concepts for world class manufacturing in the 1990's. Materials selection and use, both improved traditional and new advanced, as the latter begin to diffuse more widely, is inseparable from engineering design and the quest for higher quality, flexibility, market niching, fast product renewal, and lower cost as tools for competitive advantage in today's market place. Moreover, materials supplier-user inter-firm collaboration, especially in the context of modular manufacturing, is another necessary facet of the new innovation and market conditions.

Hence, national materials, industrial, science, technology, educational and trade strategies form part of a unified whole and must address in a coherent, systematic and long term view the issues identified in this paper.

## 5. CONCLUSIONS

### 5.1 Broad policy objectives in the 1990's

In this paper, we first identified the central characteristics and trends of the revolution in MSE, in section 2. We then integrated these elements with the restructuring process underway in IAC's since the early 1970's, under the auspices of the production and generalised application of information technologies. We point to the fact that great changes are occurring at the early stages of production, leading to a transformation of the traditional metals and chemicals input industries into materials producing branches permeated by the insights, practices and philosophy of the evolving MSE. Further, we pinpoint the inseparable links which have emerged between the design, processing and use of new materials and the changing needs of market demand, consumer tastes, and associated flexible production technologies, as IAC's undergo a slow and uneven transition towards post-fordist industrial organisation. The restructuring process entails also an impact on demand for traditional industrial raw materials the global resource base, corporate strategies and global location patterns, as well as the necessary large role played by the state in IAC's in promoting national competence in materials production and use, deemed necessary for current and future domestic competitiveness. We then crystalise the insights obtained from these sections into brief outline of the potential impact on, the implications for developing economies in the 1990's and beyond (section 4), and identify those policy areas that such economies must begin to offer strategic responses to.

The diffusion of microelectronics and telecommunications and, increasingly, of new materials technologies is clearly having an impact throughout manufacturing in both large-scale and small-scale industries and in traditional, labour intensive as well as newer, technologically progressive activities. What is, therefore, the Third World to produce in the 1990's, with what technologies and materials, at what scale, and where? Clearly some economies would do well concentrating on small scale, flexible specialisation type of industrial activities aimed at niche markets in specific designer dominated sectors. But this cannot be the case for all developing economies. Others, such as the NIC's and second tier NIC's, could and would profitably engage in high-value added, knowledge intensive production, including diversification into advanced materials. But where does that leave the majority of LDC's, indeed, the low-income LDC's? There is therefore an urgent need for an identification of the appropriate scientific, technological and institutional responses required across the whole spectrum of LDC's, such that such economies can negotiate and survive the major discontinuities ushered in by the information and materials revolution.

Commodity policy must at last move away from an obsessive concentration on market prices and redistribution and concentrate on the need for primary producers in sub-Saharan Africa, the least developed economies, lower-middle income and second-tier NIC's to build and acquire the necessary competences in MSE and parallel educational, engineering, testing and quality control, standards and institutional skills and structures that will enable them to use domestic resources to meet basic needs and participate in the world economy. For a primary objective of international economic policy in the 1990's, must be avoidance of the further marginalisation of that large number of economies which least afford to be cut off from the fruits of the materials information and biotechnology revolutions and from world economic activity, trade and payments.

Therefore, the issues that would loom large in policy discussions in the 90's will include the following: Institutions which can acquire, assimilate and use materials data and information; testing and standards institutes; processing and engineering capabilities as a central concern of industrial strategy giving access to MSE insights and research, and ability to transmit them to commercial application: the concerted effort by universities, government and industry regionally and internationally to divert the vast potential offered by MSE to meet basic needs utilising local resources while meeting environmental and energy constraints, and technical cooperation between professional societies, universities, institutes, research centres and industry in developing countries on a regional and international basis to meet the challenges posed by new materials and the environment.

In this, of central concern will be the point of entry and selectivity in building up scientific and materials and manufacturing engineering skills, utilising existing strengths while entering into joint ventures and technology licensing agreements, in the context of a dynamic and coherent industrial strategy, in which governments will play a role in setting priorities in a targeted approach. There are many opportunities for developing economies to enter into various stages of the materials and manufacturing cycles while judiciously building on existing strengths in domestic materials, manufacturing technology and human skills.

## 5.2 Common requirements and country needs across the differentiated spectrum of developing economies

The analysis in this paper is but a first attempt to meet the enormous task of understanding the enormous tasks of understanding the trends in MSE, its implications for high-technology and competitiveness in manufacturing industry and translating them to the future role of LDC's in the global redivision of labour. Clearly there is a large and differentiated array of developing economies, each a result of vastly different historical experience, social and institutional structures, and level of development of the productive forces. We are, therefore, only at the threshold of translating the trends identified into a set of viable, relevant policies to meet the needs and resources of individual economies.

There is a broad set of common needs which apply across the range of LDC's. This set would include the need for each economy to form a central materials body or think tank, comprising a multidisciplinary team, the task of which would be to monitor trends in materials science and technology, access and assimilate information and market trends, and translate them into a set of consistent domestic science, education, industrial, technology and trade policies and recommendations. Secondly, there arises the common need to acquire a critical mass of domestic MSE, industrial technology/engineering base, technical training and maintenance/support firms, which would impart a measure of flexibility on the economy, an ability to respond to external shocks and discontinuities, a degree of technology absorption and development capability, and may facilitate the flow of foreign capital and technology. Thirdly, and very importantly, each economy subjected to the pressures of the world market, must create or strengthen domestic measurement and performance evaluation technologies and standards, and address the issues of meeting higher quality specifications and quality assurance. The development of standards is of necessity an issue that must be addressed through international cooperation across LDC's and IAC's. And, fourthly, all economies need to address the issues of access to the proliferating materials information, scientific publications and development of data bases, all areas which again require international and regional collaboration.

Identifying and articulating individual developing country needs in the era of new materials, information technologies and biotechnologies is a formidable and complex task. Here, international cooperation can play a large and continuing role, in terms of the provision of information, techno-economic studies, monitoring of trends, development of methodology and concepts to handle trends and needs in a fast changing scientific, technological and industrial market circumstances. International and regional cooperation can provide the first basis and momentum for the formation of national materials strategies, which then feedback and are further enriched through international schemes and institutions such as the formation of IMAAC, and other existing regional institutions such as ESCAP or regional standards and research institutes in Africa, Latin America and Asia.

In this way the world community and individual economies may begin to come to terms with the complexity and enormous variety of materials, countries, resources and needs. IMAAC could therefore become the focal point of information on materials for developing economies and industry, in order to minimise the dislocations and uncertainties experienced by existing traditional commodity producers. Issues that must be addressed within individual economies, would include protection of intellectual property rights, the restriction of exports of high technology from IAC's, training programmes in high-technology, using MSE to meet basic needs, developing a metrology/engineering base, restricting the brain drain, and quality control.

# APPENDIX

## Advanced materials classes, chemical composition, processing path, properties and functional use

I. Metals

II. Structural Ceramics

III. Engineering Polymers

IV. Functional Devices: Electronics, Optical and Magnetic

V. Medical and Dental Materials

Source: Office of Advanced Materials Coordination, U.S. Bureau of Mines, Open File Report, OFR 4887, December 1987.

## I. METALS

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| A. Structural. | | | | |
| Superalloys | Co - based<br>Ni - based<br>with Cr, Mo, Cb Ta, W, Hf, Zr | Investment cast as polycrystalline, directionally solidified, or single crystal. | High strength at high temperatures; Corrosion resistance. | Jet engine components resistance wire. |
| Aluminum - Lithium Alloys | Al-Cu and Al-Mg with 1-3% Li | Conventional | Low density; high stiffness. | Aircraft skin and structure. |
| Amorphous Alloys | Fe - based<br>Co - based<br>with Al | Rapidly cooled | High hardness and tensile strength; corrosion resistance; high magnetic permeability, free of anisotropy; high electrical resistance. | Reinforcement for composites; corrosion resistance materials; magnetic applications |
| Rapidly Solidified Alloys | Al-Si; Many alloy systems | Very rapidly cooled as powders, ribbons. | Solid solubility increased; all properties altered. | High strength powder metallurgy products. |
| Superfine Particles | Many alloy systems | Liquid metal atomized to form submicron particles. | Large surface areas; paramagnetic; high reactivity; high sinterability. | Catalyst carriers; filters; sintering aids; fillers. |
| Ordered Intermetallics | Ni Al; Cu-Al-X alloys (X=Fe, Ni, Mn, Be, Co, Si, Sn) | Conventional, with annealing to obtain correct phase content and microstructure. | Resistance to corrosion and corrosion fatigue; High strength in heat-treated forms. | Structural materials with hot corrosion resistance; Jet engine components; ship construction. |

## I. METALS

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| Shape Memory Alloys | Cu-Zn-X (x=Si, Sn, Al, Ga); Cu-Zn; Cu-Al-Ni; Cu-Sn; Cu-Au-Zn; Ni-Al; Ti-Ni; others. | Conventional; shaped below transition temperature. | Regains original shape when heated above transition temperature. | Pipe clamps, sensors and actuators; orthodontic wire; eyeglass frames; specialty rivets; kinetic energy storage. |
| Copper-Beryllium Alloys | Cu-Be | Conventional | High strength increases with temperature; high fatigue resistance; high thermal conductivity. | Precision current-carrying springs; electrical connections test probes; components for robots. |
| Surface Hardened and Coated Metals | Carbides, nitrides, and borides of B, Cr, Hf, Mo, Cb, Si, Ta, Ti, V, W, Zr. Zirconia and mullite coatings. | CVD; PVD; thermal spray; plasma spray. | Corrosion, wear, and heat resistance. | Many structural applications. |
| Titanium Alloys | 6% Al, 4% V, etc. | Conventional | Low density, high strength at medium temperatures, toughness, corrosion resistant. | Airframes, skin, turbine parts. |
| Superplastic Alloys | Ti alloys<br>Superalloys | Fine grains for superplasticity, followed by heat treatment for strength. | Fewer machining and finishing steps. | Aircraft structure and engine components |

## I. METALS

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| B. Absorptive. | | | | |
| Hydrogen Storage Alloys | Li, Mg, Y, V, Cb, Pd, U, Fe Ti, $LaNi_5$ . | Conventional | Retain more H than tanks at moderate pressure; absorption and release reversible with temperature change. | Stationary or mobile storage; heat engines; water splitting; H-isotope separation; fusion reactor technology. |
| Porosity Metals | Alloys of Ni, Cr, Cu, Al, Ag, Zn, Pb. | Foamed during solidification. | Up to 98 pct. pore volume; continuous pores. | Electrode plates; catalyst carriers; filters. |
| C. Composites. | | | | |
| | Matrices of Al, Cu, Zn, Ti, Ni, Reinforcements of $Al_2O_3$ , mullite, B, and SiC fibers; SiC whiskers; $Al_2O_3$, SiC, $Si_3N_4$ particulates. | Prepreg lay up for continuous fibers; casting or CVD of matrix. | High strength and fracture toughness; low densities. | Aircraft, automotive, ship structural components; machinery, space structures. |

## II. STRUCTURAL CERAMICS

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| D. Monolithic. | | | | |
| Oxides | $Al_2O_3$; partially stabilized $ZrO_2$ (PSZ); tetragonal zirconia polycrystal (TZP); BeO; cordierite; SiO ; mullite; $Al_2TiO_5$; $Y_2O_3$; $ThO_2$. | Prepared as submicron powders; formed by pressing; sintered at high temperatures with or without pressure. | Heat resistance; strength; wear resistant; corrosion resistant. | Turbine blades; adiabatic engine components; heat exchangers; cutting tools; bearings; catalyst carriers; mechanical seals; nozzles; RF crucibles; nuclear shielding. |
| Non-oxides | SiC, $Si_3N_4$, SIALONS, $B_4C$, AlN, hexagonal BN, cubic BN, $TiB_2$, $ZrB_2$, TiN, TiC. | Prepared as submicron powders; formed by cold or hot pressing, with or without sintering aids; sintered at high temperatures, with or without pressure. | Heat resistance; oxidation resistance; strength at. | |
| E. Composites. | | | | |
| | Matrices of oxides and non-oxides; reinforcements of C, SiC, $Si_3N_4$, $Al_2O_3$, aluminosilicate fibers; SiC whiskers; PSZ particulates. | Processing not yet developed; fiber prepregs treated with slurry. | Heat resistance; improved fracture toughness; "graceful" fracture. | All the applications of monolithic ceramics. |
| | Carbon matrix/carbon fiber composites. | Continuous fiber prepregs; CVD carbon matrix. | Heat resistance; strength; low density; (needs protection from oxidation). | National Aerospace Plane skin; rockets and missiles; space structures. |

## III. ENGINEERING POLYMERS

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| F. Structural. | Polybutylene tarephthalate (PBT)<br>Polyethylene tarephthalate (PET)<br>Poly (4,4' isopropylidine diphenylene carbonate (Polycargonate)<br>Polyether sulfone<br>Polyarylate<br>Polyphenylene sulfide (PPS)<br>Polyamide-imide<br>Polyetherether ketone (PEEK)<br>Poly (Paraphenylene benzobisimidazole) (PBI)<br>Poly (Paraphenylene benzobisoxazole) (PBO)<br>Poly (Paraphenylene benzobisthiazole) (PBT)<br>Liquid crystal polymers<br>Polymer blends | Chemical reactions of resins with reagents at elevated temperatures; blow molded; injection molded; sheets; films; pultruded. | Melting temperatures between 240 C and 530 C; high strength and stiffness; low densities. | Structural materials for aircraft, automobiles, office equipment; electromagnetic interference shieldings. |
| G. Composites. | Matrices any of the thermoset resins or thermoplastics; reinforcement of glass fibers, boron fibers, carbon fibers, chopped fibers. | Continuous fiber prepregs laid before pouring or molding; chopped fibers, whiskers, and particulates added prior | Very high tensile strengths and fracture toughness; low densities. | Structural materials for multitude of applications. |

## IV. FUNCTIONAL DEVICES

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USES |
|---|---|---|---|---|
| **H. Electronic and Optical.** | | | | |
| Dielectrics | $Al_2O_3$, BeO, AlN, diamond film, MgO, polyimide. | Ceramic Sintering, CVD, polymer reaction. | Electrical insulation; thermal conductivity. | IC substrates, packaging. |
| Ferroelectrics | $BaTiO_3$, $SrTiO_3$ | Ceramic sintering | Dielectric over defined voltage range. | Ceramic capacitors |
| Piezoelectrics and Non-linear Optical Devices.<br>titanate (PLZT), | Quartz, lead zirconium titanate (PZT), lead lanthanum zirconium $LiNbO_3$, ZnO, polydiacetylene (PDA), liquid crystals. | Ceramic sintering, CVD, polymer monolayers, single crystal growth. | Piezoelectric or non-linear optical properties. | Vibrators oscillators, transducers, spark generators, optical switches, optical modulators. |
| Semiconductors | Si, GaAs, SiC, In GaAsP/InP, GaAlAs/GaAs, HgCdTe, Cd (S, Se), ZnO-$Bi_2O_3$, $V_2O_5$, In-Cu-Se/Zn-Cd-S. | Single crystal growth, CVD; molecular beam epitaxy. | Semiconducting over defined and controllable ranges; optical transparency for some uses. | Integrated circuits, solar cells, thermistors, sensors, varistors. |
| Light Emitters | GaAs, Gap, PLZT, yttrium aluminum garnet (YAG), InP. | Single crystal growth, CVD; ceramic sintering. | Electricity-tight conversion. | Laser diodes, light-emitting diodes, phosphors. |

## IV. FUNCTIONAL DEVICES

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USES |
|---|---|---|---|---|
| Optical Fibers and transparent Ceramics. | $SiO_2$, $Al_2O_3$, AlON, MgO, $Y_2O_3$-$ThO_2$, Ba-La-Zr-Al-Na-F, polymethylmethacrylate, selenide glasses. | Glass fiber pulling and chemical treatment. | Optical transparency with low loss over a range of wave lengths. | Fiber communications, IR transmitters, high pressure lamps. |
| Ionic Conductors | Beta-$Al_2O_3$, $ZrO_2$, ZnO, $Fe_2O_3$, SnO $MgCr_2O_4$-$TiO_2$. | Ceramic sintering. | Ion-specific conductivity | Solid electrolytes, fuel cells, humidity sensors, oxygen sensors, hydrocarbon and fluorocarbon detectors. |
| Superconductors | Ni-Ti, $V_3Ga$, Nb-Ti, Nb-Sn, $YBa_2Cu_3O_x$, type ceramics. | Metal-forming ceramic sintering, CVD thin films. | Zero resistance, magnetic field strength, current density, Josephson effect, Meissner effect. | High speed LSI, electromagnets for NMR imaging, magnetic levitation, power transmission, transformer cores. |
| I. **Magnetic.** | | | | |
| Metallic | SrCo, powder alloys, Nd-Fe-B, superconductors. | Metal forming | Magnetic field, permanent or electromagnetic. | Magnetic heads and tapes, transformer cores, motors, NMR imaging instruments. |
| Ceramic | $BaFe_{12}O$, $SrFe_{12}O_{19}$, $YBa_2Cu_3O_x$ type ceramics, other ferrites. | Ceramic powders, ceramic sintering, CVD. | Magnetic field, reversible polarity. | Magnetic tapes, motors, NMR. |

## V. MEDICAL AND DENTAL

| MATERIALS CLASS | CHEMISTRY AND FORM | PROCESSING METHODS | CRITICAL PROPERTIES | USES OR POTENTIAL USE |
|---|---|---|---|---|
| J. Structural. | | | | |
| | $Al_2O_3$ structures. | Fine powders sintered at high temperatures. | Biologically inert; corrosion resistant; high strength. | Bone replacements. |
| | Hydroxyapatite | Formed as a glass; cast. | Biologically compatible. | Bone and teeth replacements. |
| | Carbon fiber/ polylactic acid composites. | Chemical formation of PLA on C fiber prepreg. | Histocompatibility; dissolves as healing occurs. | Tendon replacements. |
| K. Functional. | | | | |
| | Silicone, fluoropolymers. | Chemical reaction; polymer forming. | Histocompatibility | Artificial blood vessels; heart repair soft tissues. |
| | Acrylic, methacrylic resins. | Chemical reaction; polymer forming. | Histocompatibility. | Artificial Kidneys. |